RESOURCE POTENTIAL AND BARRIERS FACING THE DEVELOPMENT OF ANAEROBIC DIGESTION OF ANIMAL WASTE IN CALIFORNIA

CONSULTANT REPORT

Prepared For:
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Prepared By:
Mark A. Moser
Resource Conservation Management Inc.

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Prepared for the California Energy Commission
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by

Mark A. Moser
Resource Conservation Management, Inc.
P.O. Box 4715
Berkeley, CA. 94704
(510) 658-4466

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I. Abstract

The report addresses production, recovery and use of methane from animal manures, the associated costs and potential benefits in California. Manure management issues and energy production issues are discussed. Regulations affecting manure management in California are summarized. Technical, economic and institutional barriers to biogas utilization are presented. Biogas production potential on California farms is quantified. Commercially demonstrated digester types including covered lagoons, complete mix and plug flow digesters are identified and described. Biogas collection, handling and use options are summarized. Component costs are presented. A model for estimating the costs and benefits of anaerobic digesters in California is introduced. The sensitivity of the Net Present Value of digesters to variations in component costs is described. The model is tested against data from an operating digestion system. Supplemental information on technical topics is included in ten appendices.

It was determined that the biogas resource available from livestock manure in California is equivalent to 57 megawatts of electric power. In addition, the size of the livestock facility was found to be the most important factor in the profitable application of anaerobic digesters on California livestock farms.

Acknowledgments

The author wishes to thank the California Energy Commission for the opportunity to prepare this report. The author thanks Dara Salour, project manager and George Simons, Section Director, Development Division for their guidance and patience in this project. The author thanks James Young of the CEC and acknowledges his contributions in developing Chapter 4 - Biogas Production Potential on California Dairy Farms, Chapter 9 - Regulatory Impact on the Development of Biogas Facilities on California Dairy Farms and for collecting and preparing data on energy usage included in Appendix J.

I. Abstract

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II. Executive Summary

This report addresses production, recovery and use of methane from animal manures and the associated costs and potential benefits in California. Development of large animal confinement facilities over the past 20 years has concentrated manure sources. Air and water quality issues associated with these sources resulted in increased regulation of the handling, storage and utilization of manures.

Anaerobic digestion is a natural process that yields methane gas from decomposition and biological stabilization of organic materials. Concentrated manure sources are potential opportunities for production, recovery and use of methane gas as an energy source. Other benefits from methane production are odor reduction, pathogen reduction and byproduct recovery.

Methane production can be accomplished in a designed anaerobic digester structure or in properly designed anaerobic lagoons. An anaerobic digester system is designed to optimize methane bacterial growth and biogas production. An anaerobic digester system includes manure collection, pretreatment, an anaerobic digester, byproduct recovery, biogas recovery, biogas handling and biogas use. Three digester types - covered lagoons, complete mix and plug flow digesters are demonstrated to be commercially viable in California. Methane recovered from animal waste can be used to fuel engine-generators to produce electricity, boilers to produce hot water and adsorption chillers to produce chilled water.

The quality or methane generation potential of the manure is directly impacted by the collection and storage methods used. Dairy and hog production facilities are the most likely candidates for anaerobic digesters in California because of their regular manure collection schedule and their virtually constant use of energy.

With the current animal waste management practices, California dairies have a potential of generating over 20 million cubic feet of methane, or over 34 million cubic feet of biogas (assuming biogas contains 60% of methane) every day. If this biogas resource were fully utilized to generate electric power, the net power generating potential would be 57 megawatts.

This project has also developed the California Methane Estimation Model (CMEM) to estimate costs and benefits of methane recovery and use. The CMEM model was used as the basis for identifying key factors that affect the profitability of anaerobic digestion systems on California livestock farms. The model uses input values for animal numbers, farm location, farm characteristics and waste management techniques to select an appropriate digester type and costs. Biogas potential is also used to calculate potential revenues. Costs and revenues are taken into a spread sheet where the Net Present Value of the project is calculated. The model is for prefeasibility estimation purposes only. Individual farms have specific characteristics and equipment that should be addressed in a formal feasibility and design study.

Using reasonable cost and revenue assumptions, many anaerobic digester systems could be built in California that would have a positive NPV. The size of the farm is the most important factor, because larger facilities take advantage of significant economies of scale. The value of products must support the level of investment necessary to build a digester system. Current energy prices could justify many profitable digesters in California. However, the future value of electricity is very important and the most difficult to accurately analyze in general models, given the flux in utility deregulation. The capital cost factors, if they can be reduced, could significantly affect the NPV of potential projects. Each project must be analyzed in detail for the specific site conditions to determine its viability.

The model was tested against monitoring data for actual operations of Sharp Ranch's hog waste covered lagoon. The model predicted the benefits realized at Sharp Ranch quite accurately, however due to the conservative loading rate limits, the lagoon and cover were predicted to cost about 25% more than the actual construction costs. When actual measured temperature and loading rates were input into the model, the model was reasonably close to predicting the average electrical output.

There are no technical barriers to anaerobic digestion. There are many other barriers to commercialization of biogas technology including a history of poor performance, a lack of people and institutions familiar with successful projects, high capital costs, limited financing opportunities and most importantly, disadvantageous electric utility rate structures.

The solutions to most of these barriers are education and information on successful digesters. The utility barrier may be the most difficult. To overcome the utility barrier a mechanism to financially reward the utility is necessary. There is very little current research on anaerobic digestion and on biogas use. However, programs such as AgSTAR, a joint USEPA, USDOE and USDA program, are again promoting anaerobic digester systems based on the successful installations of the 1980s.

III. Introduction

This report addresses production, recovery and use of methane from animal manures and the associated costs and potential benefits in California. Methane production, recovery and use is virtually the only manure treatment process that has a potential for a profitable return on investment. Methane production can be part of, but not a replacement for, a manure management system.

General Manure Management Issues

Manure management is an unavoidable cost with minimal return on investment. Improper manure management resulting in air, surface water, groundwater, or soil pollution may lead to punitive fines, legal fees, or business closure. An increasingly costly driving force in manure management is odor control to limit exposure to nuisance lawsuits. Odor control is typically achieved through a properly designed manure treatment process as part of a manure management system.

Manure Management Issues in California

California produces large quantities of milk, meat and eggs from confined animal agriculture. Animals produce manure which requires proper management to limit potential pollution. Development of large animal confinement facilities over the past 20 years has concentrated manure sources. Air and water quality issues associated with these sources resulted in increased regulation of the handling, storage and utilization of manures.

Manure Management and Energy Production Possibilities

Anaerobic digestion is a natural process that yields methane gas from decomposition and biological stabilization of organic materials. Concentrated manure sources are potential opportunities for production, recovery and use of methane gas as an energy source. Other benefits from methane production are odor reduction, pathogen reduction and byproduct recovery.

Methane production can be accomplished in a designed anaerobic digester structure or in properly designed anaerobic lagoons. Methane recovered from animal waste has been used to fuel engine-generators to produce electricity, boilers to produce hot water and adsorption chillers to produce chilled water.

History of Anaerobic Digesters in California

The history of on farm biogas production and utilization systems in California is relatively poor. Therefore, the general impression of costly, unreliable technology is a barrier to future implementation.

The tax incentives of the late 1970's and early 1980's encouraged the construction of approximately 16 digester systems, often for the tax benefits. Two of those were later rebuilt making a total of 18 units. Table 3.1 lists these digesters and their status.

Only 5 of those systems are running today and 3 of these are on pig farms owned by one family. Of the other two, one is a very successful dairy plug flow digester and one is a dairy thermophilic complete mix research unit.

The failures have had a much greater impact than the successes. Most of the failures were at well known dairy farms operated by leaders of the industry. These failures have been widely discussed and publicized as significant economic losses to their owners. The successful units are viewed as exceptions to accepted wisdom that anaerobic digestion doesn't work.

Even more important is the lack of appreciation by the farm community of why systems operated or did not operate. Several very costly technical failures were due to bad design and a lack of understanding by the system developer. Simply, the owner made a poor buying choice.

Economic failures occurred where the digester system debt payments and operation cost exceeded the value of the revenues. Several factors including excessive initial investment, poor equipment selection with resultant high maintenance costs, or reduced value of the outputs caused shutdown of digesters. Technical successes became economic failures.

Table 3.1 California Digester Systems Status

Digester Type - Name		Years of Operation - Current Status
Covered Lagoon		
(V)	Farmer Bob	2 years - Left Business
(P)	**Sharp - Sharp Ranch**	**10 years - Operating**
(P)	**Sharp - Royal Farms**	**14 years - Operating** 75-150 kW Waukesha
(P)	**Sharp - Fresno**	**8 years - Operating**
(D)	Luiz	Nonoperational - Technical Failure
(D)	Kahler	Operated - Status Unknown
Plug Flow		
(D)	Grossi	8 years - Left Business
(D)	Bignami	2 years - Technical Failure
(D)	BET Genetics	Left Business Prior to Startup
(D)	**Langerwerf**	**14 years - Operating** 75 kW Cat 3306
(D)	Luiz Rebuild	2 years - Economic Failure
(D)	Sawyer	1 year - Technical Failure
(D)	Kutzier	1 year - Technical Failure
(D)	Martignoni	4 years - Economic Failure
Complete Mix		
(D)	Amen	Occasional Operation - Status Unknown
(C)	Nunes	3 year operation - Economic Failure
(D)	**Martignoni Rebuild**	**3 years - Operating, thermophilic research**
(D)	Van Werdhuisen	Technical Failure - Background unknown

(C) - Laying hens (V) - Veal calves
(D) - Dairy (P) - Pig

Barriers to Commercialization of Biogas

There are many barriers to commercialization of biogas technology including a history of poor performance, a lack of people and institutions familiar with successful projects, high capital costs, limited financing opportunities and most importantly, disadvantageous electric utility rate structures.

The solutions to most of these barriers are education and information on successful digesters. The utility barrier may be the most difficult. To overcome the utility barrier a mechanism to financially reward the utility is necessary.

Technical Barriers

There are no technical barriers to anaerobic digestion. Digester designs have been proven on farms in the US over the last 15 years. While there are more non-operating units than operating units, there are over 20 very successful systems with long track records to verify that all major technical questions have been answered.

While digester installation in the US has fallen off in the past 10 years, approximately 100 European and 5,000 Taiwanese digesters have been built. These systems rely on the same principles and design techniques used in successful systems in the US.

Economic Barriers

One of the major barriers to anaerobic digester systems is the initial capital cost. Most systems that will have a positive cash flow cost in excess of $200,000. This is a sizable investment, even for large farms. Farmers are not comfortable with these large investments which have an uncertain reputation.

Institutional Barriers

There are a multitude of institutional barriers to be overcome.

Regulatory

In general, there are no regulatory barriers to the technology. All agencies who deal with manure management regulation have welcomed digesters for their potential to assist in proper manure management. The level of regulatory control over construction permits, operation permits and air permits varies from county to county, but no county has any special regulatory barrier to anaerobic digestion, per se.

State Farm Advisors/Ag Extension

Farm advisors and agricultural extension agents can be barriers to use of anaerobic digestion technology. They generally have little formal training or experience in manure management. Their experience with the digestion technology is also limited. Lacking experience and being conservative by nature, these people become barriers by hedging their support for digester technology.

University of California and California State University have historically not offered agricultural waste management courses and students therefore have not had the opportunity to study manure management or anaerobic digestion technology and take that knowledge back to the farm. These institutions become barriers do to a lack of familiarity with technology. As of fall 1996, UC Davis is offering a course in agricultural waste management.

Federal Agencies

Federal agencies have been barriers in much the same way as the Universities. However, these agencies are recognizing their past oversight. In reviewing the successful application of anaerobic digestion technology in odor, pollution and methane control there is a change in attitude and policy occurring.

The USEPA, USDOE and USDA have launched the AgSTAR program to promote methane production, recovery and use on farms through anaerobic digestion systems. The AgSTAR program is trying to first educate agency personnel who have direct contact with farmers to promote development of successful, economically viable anaerobic digestion technology.

Financial

The inability to finance a digester system is a barrier. Typical farm credit organizations will only give loans based on a farmer's ability to repay a loan for a digester independent of any revenue stream from the system. Few if any credit sources will recognize the revenue stream associated with an anaerobic digestion system.

Non-traditional financing such as lease financing is limited to portions of the system that can be removed and resold. Venture capital is available, however, the interest rates that these firms charge is usually so high as to cancel the economic benefit of the system.

Federal cost sharing programs for manure management are being expanded to include a portion of the cost of a digester system. The cost share limit is also being increased so that a farmer may receive up to $50,000 for one activity rather than $5,000 a year for 10 years.

State energy loan programs are available and often quite reasonable. However, the other barriers discussed have been diverting farmers before they have a chance to investigate this financing option.

Utility

The most formidable barrier to the development of anaerobic digestion is the utilities' attitudes and rate structure. The utility controls the value of the electricity production of a farm digester.

The utility must be willing to cooperate with a farmer so that the farm can produce a portion of its own power. However, California utilities have been very clear since the mid 1980's that they do not need or want independent power producers.

The utilities make this clear by:

1) Selling electricity as a composite commodity with up to 7 parts. (see explanation below)
2) Selling electricity to farm customers through a bewildering variety of rate structures.
3) Offering to pay a price below the cost of production for any excess electricity that a farm might produce and sell.
4) Requiring expensive intertie equipment.
5) Putting all plans through an exhaustive and time consuming review processes.

The major barrier is composite electric rates. For example a farm may pay $0.09/kWh for electricity. However, (in a simplified manner) the farm is billed $0.045/kWh used, $0.04/kW for demand, and $0.005 as a basic service charge. These rates may also change seasonally and during various peak, partial peak and off peak usage times.

The demand charge is a key problem. Demand is the highest rate of electricity consumption measured over any 15 minute period during a month. A good farm biogas system is operational 85% of the time, while a utility power plant is considered excellent with 80% availability. An excellent farm biogas system is operational 92% of the time, however demand charges are recorded in any month where the farm engine-generator is not operational 99.97% of the time. This level of operation is a virtual impossibility over any extended period because regular maintenance requirements such as oil changes often exceed 15 minutes. Demand rates have been carefully crafted so that the utility makes full profit if the farm buys electricity for more than 15 minutes a month at its full load.

Purpose of this Report

Why is this Report Necessary?

This report was prepared at the request of the California Energy Commission to update the resource potential of biogas generated from livestock manure in California and to consolidate information on anaerobic digesters that has become available in the last 20 years. In addition, the California Methane Estimation Model (CMEM), was developed to estimate the costs and benefits of methane recovery and use; and to identify key factors affecting the profitability of anaerobic digestion systems on California livestock farms.

Reasons for Focus on Dairies and Hog Farms

This report focuses on dairies and hog farms since anaerobic digesters require daily manure feed to produce a consistent level of biogas. Dairy and hog production facilities are the most likely candidates for anaerobic digesters in California because of their virtually constant use of energy and their regular manure collection schedule.

Most egg producers would not be able to benefit from methane production because manure in modern "high rise" egg ranches is only cleaned out semi-annually. Older "flat houses" might successfully produce methane because manure is recovered regularly. However, most chicken manure is hauled offsite dry and water addition necessary for digestion would add significant weight and volume to the amount to be hauled and would be cost prohibitive. Chicken manure has the potential to produce far more energy than could be used on the farm.

Broilers and turkeys are raised on litter (sawdust or rice hulls) using minimal energy and producers only collect the manure-litter mix every 9 - 18 weeks. The irregular collection of manure and dilution with undigestible material precludes anaerobic digestion of broiler and turkey manure.

Similarly, most beef cattle feeding occurs in large dry lots with minimal energy use and infrequent manure collection. Therefore, the target farm types for this report are dairy and hog farms where manure from animals is recovered regularly.

Outline of the Report

Chapter IV summarizes the biogas production potential on California dairy farms. Chapter V characterizes anaerobic digestion systems, identifies digester component capital costs, and introduces the California Methane Estimation Model. The model estimates methane production from different farm and digester types and capital, operating and maintenance costs of various digester technology options. Chapter VI characterizes biogas usage including major gas use components, their cost and operation and maintenance costs. Chapter VII discusses component costs and benefit values that affect the profitability of a biogas system. Chapter VIII compares model predictions for a hog farm with an actual covered lagoon system. Chapter IX discuses regulations that impact manure management and biogas development. Chapter X summarizes the report and discusses future research. Appendices A - J include supporting information and data for the report.

IV. Biogas Production Potential on California Dairy Farms

Biomass Resources in California

Manure generated in livestock farming operations is potentially the largest biomass resource in California. In the California Energy Commission's *1991 Biomass Resource Assessment Report for California,* the total biomass resource in California was estimated to be 47 million bone dry ton (BDT). This is equivalent to 740 trillion British Thermal Units (BTU) of potential energy, or nearly 10% of the energy consumption in California in 1990. Resources included in this assessment were: residues from field and seed crops, fruit and nut crops, lumber mill waste, urban wood waste, urban yard wastes, livestock manure and chaparral. Livestock manure is the most abundant resource among them, accounting for over 25% of the total biomass resources. The total energy potential of livestock manure in 1991 was 173 trillion BTU.

Animal Manure Resources in California

The estimated livestock manure resource includes manure collected from cattle (beef, dairy and others), chickens (layers), pigs, sheep, and turkeys. Cattle feeding facilities are by far the dominant animal manure producers. The estimated energy potential of cattle feedlot manure in 1991 was 148 trillion BTU, or 86% of the total energy potential of livestock manure in the State.

Animal Manure Resource on California Dairy Farms

Although anaerobic digestion of animal manure is a readily available technology, it is limited by the type of feed a digester can receive. Common digesters use manure that is between 2-13% solids. Manure has to be fresh for proper microbial reaction to take place in the digesters. To achieve this, animal manure has to be collected weekly, if not daily. At the present time, this manure management requirement is only met on dairy, hog and a small number of chicken farms. Since hog farms are relatively small in number (with the number of hogs in the State being approximately 1/5th the number of dairy cows), the resource potential of hog manure is not studied further in this chapter. However, the model developed as a part of this project is validated using data from a successful digester system on a hog farm (Chapter 8). Chicken farms will also not be considered because chicken manure is currently sold profitably as fertilizer. In addition, many chicken operations do not have the land necessary to support an anaerobic digestion system.

The animal manure resource study is therefore focused on dairy farms in California. In order to assess the energy potential of biogas generated on California dairy farms, on-farm waste management techniques need to be taken into consideration. The quality or methane generation potential of the manure is directly impacted by the collection and storage methods used.

Dairy Manure Management Practices in California

Two of the sources of data used in this chapter are the South Valley Study conducted by Mark Moser for the USEPA and the California Dairy Cost Analysis data from the Milk Stabilization Branch of the California Department of Food and Agriculture (CDFA). Both studies revealed that there are three prevailing manure management schemes used on California dairies. These manure management schemes are based on the dairy housing patterns and manure deposition characteristics. The most notable difference between dairies is in cow housing. Manure management is relatively similar among dairies with similar cow housing situations.

Dairies using one of these manure management schemes have been identified as a member of a particular dairy type. The three dairy types are as follows:

1. Flushed freestall
2. Drylot with feedlanes flushed
3. Scraped drylot

A freestall flush dairy generally includes a milk barn and separate-roofed freestall barns for feeding and resting. Most freestall flushed dairies have drylots for cow lounging. A freestall barn usually accommodates only the milk cow herd. The milking parlor floor is cleaned by hose or flushed with fresh water. Flushed water containing manure is collected at the end of the flush lane and piped either to a separator or to the storage lagoon.

A flushed drylot dairy has a milk barn and drylots with flushed feedlanes. The parlor floor is cleaned by hosing or flushing with fresh water. Flushed water containing manure is collected at the end of the flush lane and piped either to a separator or to the storage lagoon. A significant portion of the manure is deposited in drylots and scraped at random intervals as solid manure. The solids are often scraped into piles and left until there is an opportunity to haul them away.

Most scraped drylot dairies are older dairies. Eighty-five to ninety percent of the manure is managed by dry scraping and truck removal. Drylot feedlanes usually do not have curbs and are not cleaned by flush water. Due to infrequent collection the manure in scraped drylots has decomposed and become unusable for anaerobic digestion. Manure collected fresh (such as flushed manure) has greater methane generation potential due to the retention of volatile solids. Many dairies have solid separators to reduce solid loading in storage lagoons. This results in the reduction of volatile solids in the lagoons and lower methane yield. More detailed information on dairy types is contained in Appendix A.

The California Dairy Cost Analysis divides California into six dairy regions, shown in Figure 4.1. The dairy waste management techniques employed in each region are directly related to the availability of water and agricultural land and prevailing regional weather patterns. For example, in Southern California, the majority of the dairies are of the scraped drylot variety because water is scarce. In contrast, the newer South Valley dairies are mostly of flushed freestall variety due to plentiful water supply and agriculture land. The regional distribution of dairy types are presented in Figure 4.2.

Biogas Resource Potential on California Dairies

The third source of data for this chapter is the *California Dairy Industry Statistics* published by the California Department of Food and Agriculture (CDFA). Figure 4.3 presents the regional dairy cow population and methane production potentials. The assumptions made in calculating methane production potential can be found in Appendix B. As can be seen from this figure, the methane production potential in Southern California is significantly less than that of the South Valley region. This is due to the poor manure quality resulting from the widespread use of drylot type dairies in Southern California. However, in the South Valley region, manure quality and consequently the methane production potential is high due to the use of flushed manure management systems. Clearly, the South Valley region has the highest methane production potential in California, as well as the highest cow population. The detailed source information and calculations can also be found in Appendix B. Table 4.1 is a summary of methane production estimates for the different types of dairies in California.

Table 4.1 Daily Methane Production Potentials on California Dairies.

Type of dairies	# of Cows	# of Animal Units (AU)[a]	Unit potential CH_4 (ft^3/AU)[b]	Daily potential CH_4 (ft^3)
Flushed freestall	371,254	519,756	23	11,954,388
Flushed drylot	261,367	365,914	17	6,220,538
Drylot	567,653	794,714	3	2,384,142
Totals	1,200,274	1,680,384		20,559,068

a. Animal Unit = 1 animal count × 1.4.
b. Screen solids separators are used.

Table 4.1 indicates that the flushed manure management systems, especially the flushed freestall systems provide greater opportunity for methane recovery due to the high frequency of manure collection, which results in fresh manure and more effective methane production.

In conclusion, with the current animal waste management practices, California dairies have a potential of generating over 20 million cubic feet of methane, or over 34 million cubic feet of biogas (assuming biogas contains 60% of methane) every day. The energy content of this biogas resource is over 20 billion BTUs, using its estimated higher heating value. If this biogas resource were fully utilized to generate electric power using engine-generator sets at a heat rate of 15,000 BTU/kWh, the net power generating potential would be 57 megawatts.

Widespread use of biogas technology on dairy farms would not only provide a readily available energy source for on-farm use, but also offer solutions to many environmental problems facing dairy farmers. The environmental benefits include the reduction of odor and pathogens from manure sources. The following two chapters characterize anaerobic digesters and biogas transmission, handling and use technologies.

References

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2. California Dairy Industry Statistics 1993, Dept. of Food and Agriculture, Sacramento, CA, 1994.
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6. Spivey, Walt. Cost Analyst, Milk Stabilization Branch, Department of Food and Agriculture, Personal interviews, Sacramento, CA. November 1994.

Figure 4.1 Dairy Regions in California

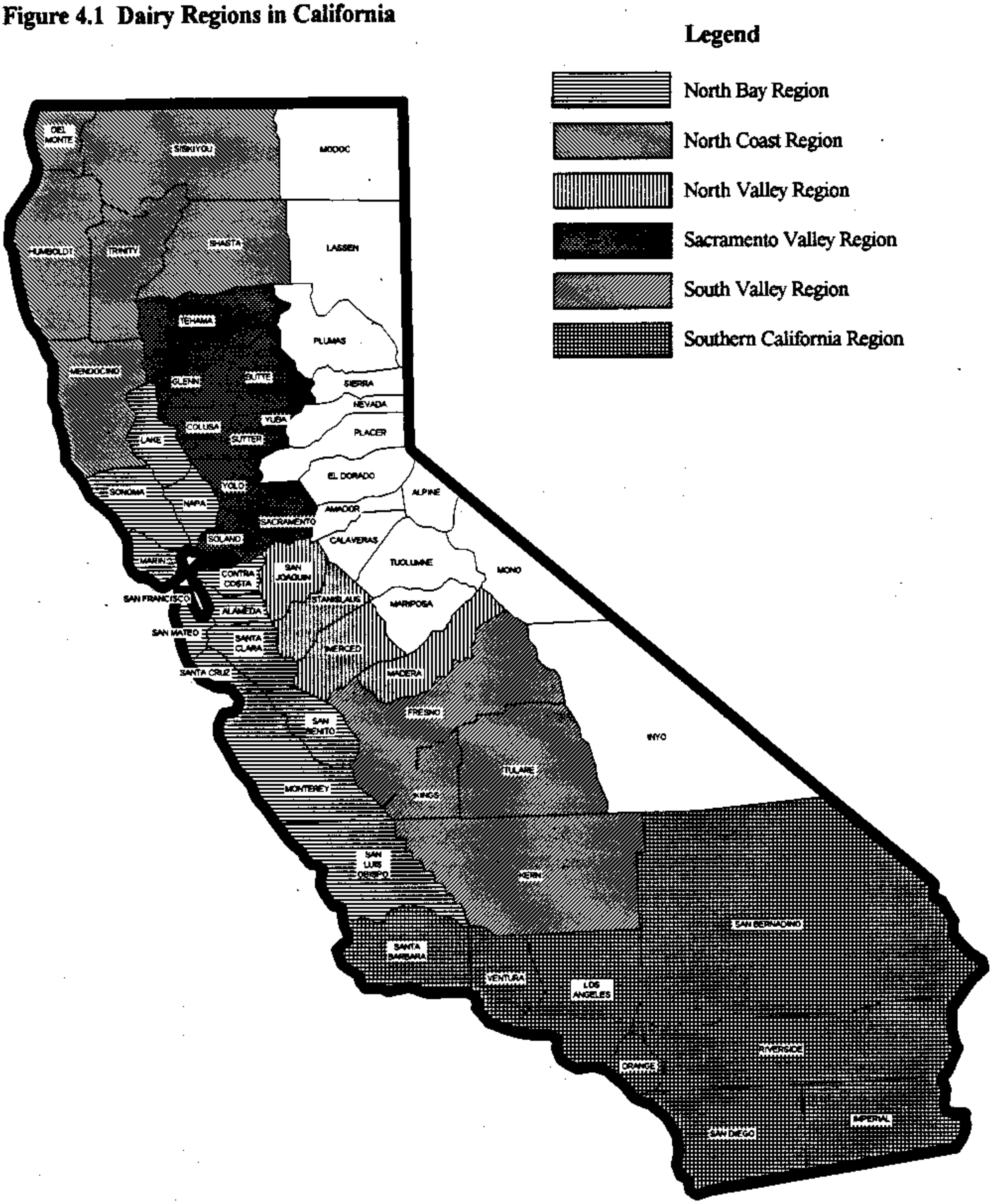


Figure 4.2 Distribution of Dairy Types in California

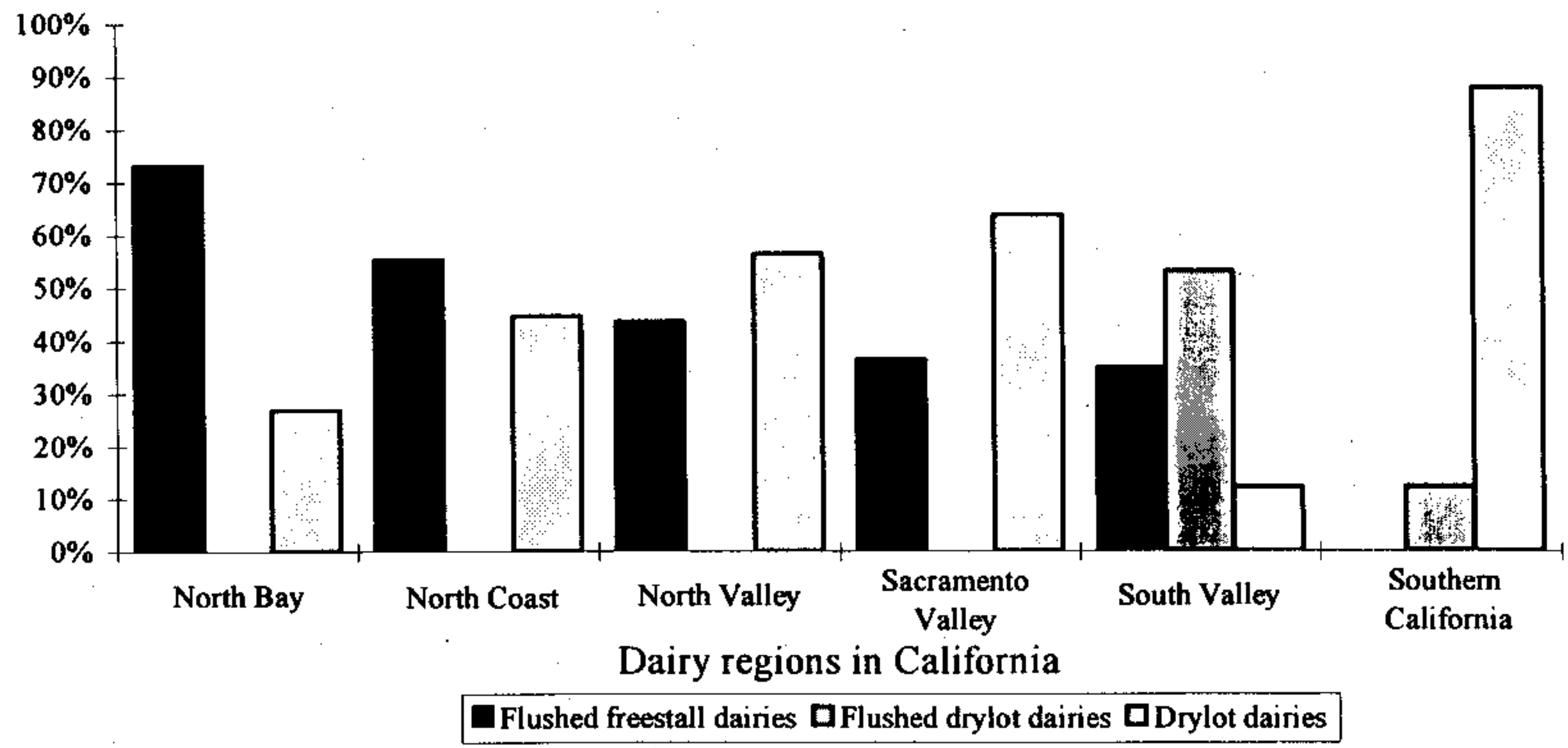
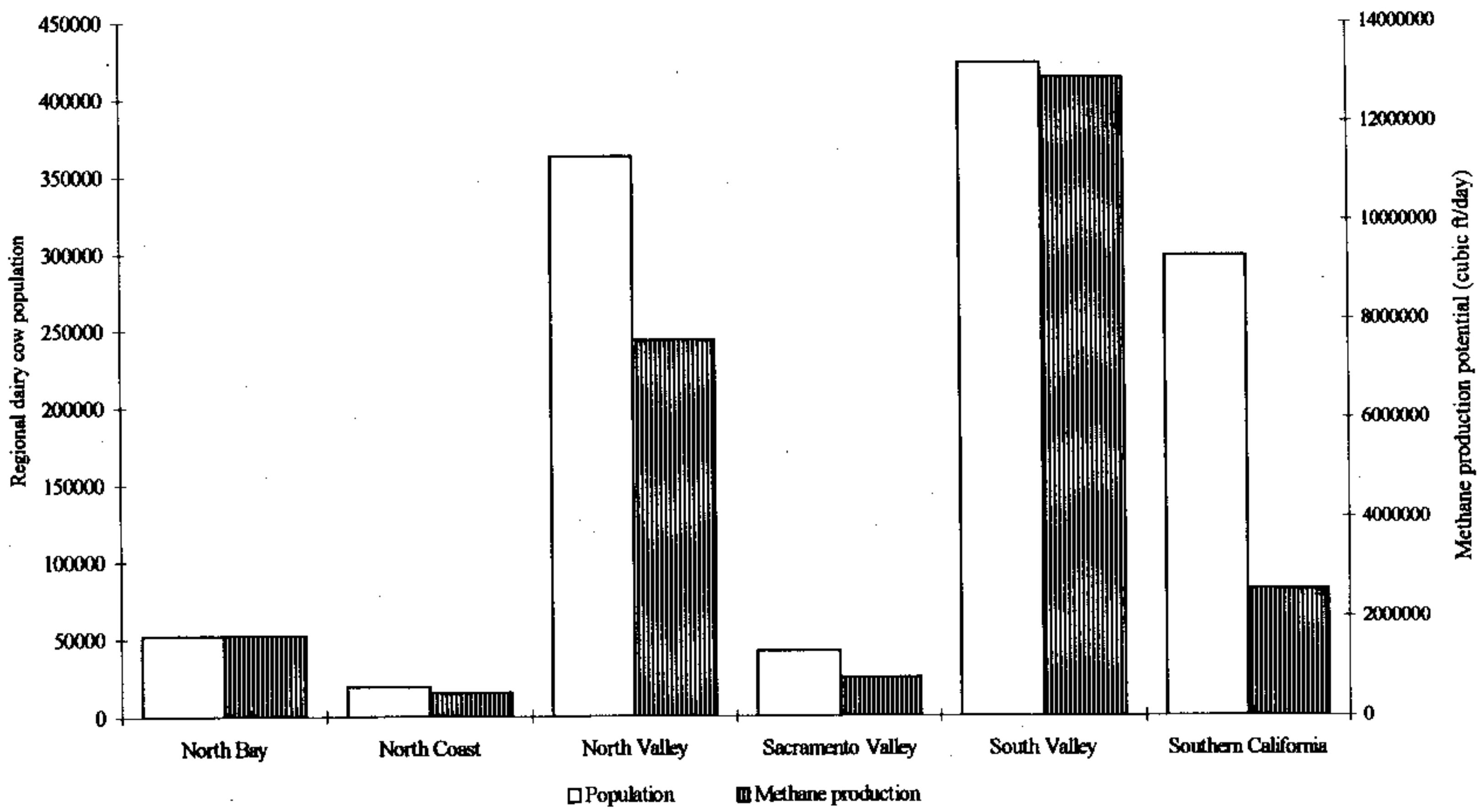


Figure 4.3. Regional Dairy Cow Population and Methane Production Potential Comparison



V. Characterization of Anaerobic Digesters

Introduction

This chapter will introduce anaerobic digestion technologies, their components and costs. The California Methane Estimation Model (CMEM) will be introduced.

Characterization of Anaerobic Digesters

Anaerobic Digestion Process

Manure consists of partially decomposed feed, waste feed and water. Manure alone or mixed with process water and flush water is generally too concentrated to be decomposed aerobically in a manure treatment or storage structure, because oxygen cannot diffuse into solution fast enough to support aerobic bacteria. Therefore, manure is broken down sequentially by groups of anaerobic bacteria.

Anaerobic digestion is a complex process that can be simplified and grouped into two stages, summarized in Figure 5.1. The first stage decomposition is performed by ubiquitous and fast growing acid forming bacteria. Protein, carbohydrate, cellulose, and hemicellulose in the manure are hydrolyzed and metabolized into short chain acids such as acetic acid, butyric acid, and proprionic acid, and longer chain organic acids. This stage is easy to recognize because the decomposition products have noticeable, disagreeable, effusive odors.

Organic acids can be metabolized by methane forming bacteria, producing a mixture of methane and carbon dioxide called biogas. Methane bacteria are a small group of slow growing, environmentally sensitive bacteria. These bacteria require a pH greater than 6.5 and adequate time to convert organic acids into biogas. Methane bacterial growth and methane production slows as water temperature decreases. The amount of time manure remains in a digester is called the hydraulic retention time (HRT) and is defined as the digester volume divided by daily influent volume.

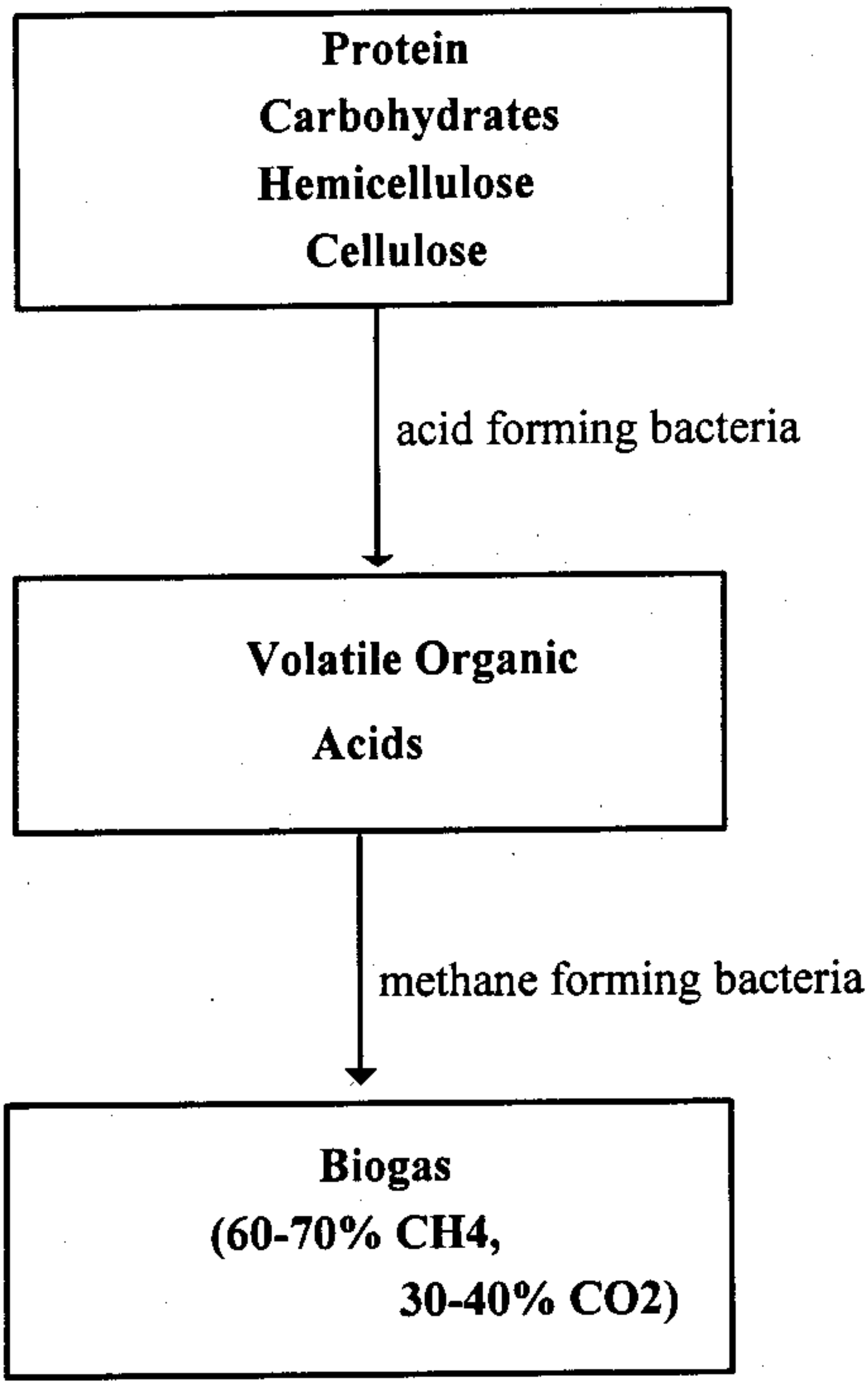
Biogas from a stable methane production process contains a minimum of 60% methane. However, long retention time anaerobic decomposition will yield biogas containing up to 85% methane. Biogas is virtually odorless but contains some mercaptans that odorize the gas.

General Effect of Digestion on Nutrient, Pathogen and Weed Seed Content in Waste

A digester will have minimal effect on the total nutrient content of the digested manure. However, the chemical form of some of the nutrients will be changed. A digester will decompose organic materials converting approximately half or more of the organic nitrogen(Org-N) into ammonia (NH_3-N). Some phosphorus (P) and potassium (K) are released into solution by decomposing material. A minimal amount of the P and K will settle as sludge in most digesters. However, 30 - 40 % of P and K are retained in covered lagoon digesters. Dissolved and suspended nutrients will flow through the digester.

Digesters are very effective in denaturing weed seeds and reducing pathogens. Pathogen reduction is greater than 99% in a 20 day HRT mesophillic digester.

Figure 5.1 Simplified Processes of Biogas Production



Anaerobic Digester System Components

An anaerobic digester system is designed to optimize methane bacterial growth and biogas production. The system includes manure collection, pretreatment, an anaerobic digester, byproduct recovery, biogas recovery, biogas handling and biogas use. The components are described in the following sections.

Manure Collection

Manure must be collected fresh on a regular schedule for digestion. In California, manure is collected as a semi-solid or solid with a tractor scraper or as a thin slurry by flushing water over a curbed concrete alley where manure is deposited. A very important consideration is the amount of process water included in the manure collection. Process water includes all water from all sources that mixes with manure. Typical manure collection techniques in California have been discussed in Chapter 4 and Appendix A.

Pretreatment

Collected manure may undergo pretreatment prior to introduction in a digester system. Pretreatment is used to adjust the manure or slurry contents to meet process requirements of the selected digestion technology. A collection/mix tank may be used to accumulate manure, process water and/or flush water. Proper design of a mix tank prior to the digester can limit the introduction of sand and rocks.

A collection/mix tank is a concrete or metal structure where manure is deposited by a manure collection system. For digesters requiring thick slurry, a mix tank serves a control point where water can be added to dry manure or dry manure can be added to dilute manure.

For digesters where solids should not be introduced, manure mixed with flush and process water can be pumped from the collection/mix tank to a solids separator. A variety of solids separators are available and are currently used on farms.

Anaerobic Digester

An anaerobic digester is an engineered containment vessel designed to promote the growth of methane bacteria. The digester may be heated or unheated, mixed or unmixed, a simple tank or a very complicated media packed column. Manure characteristics and collection technique determine the type of anaerobic digestion technology that can be used. The next section describes the characteristics of various anaerobic digestion technologies.

Byproduct Recovery

It is possible to recover digested fiber from the effluent of some ruminant manure digesters. There is no valuable solid byproduct that is easily recoverable from digestion of non-ruminant manures. Digested solids are a valuable product for cattle bedding or sale as a soil amendment.

Biogas Recovery

Biogas formed in a digester bubbles to the surface and may be collected by a fixed rigid top, a flexible inflatable top or a floating cover depending on the type of digester. The collection system directs biogas to gas handling components.

Biogas Handling

Biogas may be filtered for mercaptan and moisture removal. Biogas is usually pumped or compressed to operating pressure and then metered to the gas use equipment.

Biogas Use

Recovered biogas can be used as fuel for heating, adsorption chilling or an engine to drive an electric generator.

Available Anaerobic Digestion Technologies

Many configurations of anaerobic digesters have been developed but may or may not be commercially available for California farms. This section briefly describes digester types and a later section gives detailed discussion of digester types suitable for California dairies. Table 5.1 lists the operating characteristics of digester technologies.

Table 5.1 Types of Digesters and Their Characteristics

Type of Digester	Level of Technology	Influent Solids Concentration	Solids Allowable	Supplemental Heat	HRT (days) (1)
Ambient temperature covered lagoon	low	0.1 - 2%	fine	no	40+
Complete mix	medium	2.0 -10%	coarse	yes	15+
Plug flow	low	11.0 -13%	coarse	yes	15+
Packed reactor(2)	medium	0.5 - 2%	soluble	yes	2+
Upflow anaerobic(2) sludge blanket	high	0.5 - 2%	soluble	yes	2+
Anaerobic sequencing batch reactor (2)	experimental	0.5 - 8%	coarse	yes	2+
High solids	experimental	20 - 35%	coarse	yes	15+

(1) HRT = Hydraulic Retention Time = digester volume/daily influent volume

(2) Attached growth reactors

Ambient Temperature Covered Lagoon

Properly designed anaerobic lagoons are used to produce biogas from dilute wastes with less than 2% total solids (98% moisture) such as flushed dairy manure, dairy parlor washwater and flushed hog manure. The lagoons are not heated and the lagoon temperature and biogas production varies with ambient temperatures. Coarse solids such as hay and silage fibers in cow manure must be separated in a pretreatment step and kept out of the lagoon. If dairy solids are not separated, they float to the and form a crust. The crust will thicken, reducing biogas production and eventually filling the lagoon.

Several unheated, unmixed anaerobic lagoons have been fitted with floating covers for biogas recovery from hog waste in California. Other industrial and dairy covered lagoons are located across the southern US in warm climates.

Complete Mix Digester

Complete mix digesters are the most flexible of all digesters as far as the variety of wastes that can be accommodated. Wastes with 2 - 10% solids are pumped into the digester and the digester contents are continuously or intermittently mixed to prevent separation. Complete mix digesters are usually above ground, heated, insulated, round tanks. Mixing can be accomplished by gas recirculation, mechanical propellers or liquid circulation.

One intermittent mix digester has been built at a dairy in California and operated with varying results due to seasonal pasturing of cows. Another was built for layer manure and functioned well for four years.

Plug Flow Digester

Plug flow digesters are used to digest thick wastes (11 - 13% solids) from ruminant animals. Coarse solids in ruminant manure form a viscous material and limit solids separation. If the waste is less than 10% solids, a plug flow digester is not suitable. If the collected manure is too dry, water or a liquid organic waste such as cheese whey can be added..

Plug flow digesters are unmixed, heated rectangular tanks. They function by displacement of old material by new material horizontally through the digester. New material is usually pumped in, displacing an equal portion of old material out of the digester.

Several plug flow digesters have been built in California. However, poor design by several companies resulted in a high rate of failure.

Attached Growth - Packed Reactor or Upflow Anaerobic Sludge Blanket (UASB)

Packed bed digesters are considered experimental for manures but could be considered for treatment of screened flushed manure and parlor process water. Anaerobic bacteria are retained in the digester either on the surface of packing materials or in a sludge blanket and digest material from solution as it passes by. A packed reactor will contain spheres, plastic baffles, or wood bats as media.

This approach is most successful for dilute, soluble organic wastes. Wastes with particulates plug or overload these digesters. These designs are often used where space is limited. Tank volume is substantially reduced compared to other digester designs, while the amount of equipment to operate the digester is substantially increased.

A pilot scale packed bed reactor was operated at a dairy in Florida for 6 months in 1994 and a full scale dairy reactor is under construction at the University of Florida. Appendix F includes additional information on attached growth digestion.

At this time, full scale use of this technology has not been demonstrated on farms in the United States and therefore will not be considered further.

Anaerobic Sequencing Batch Reactor (ASBR)

At this time ASBR technology is experimental. An ASBR treats waste in small batches. Waste and settled sludge are pumped into the partially filled digester. The batch is mixed for several hours then mixers are shut off and particulates are allowed to settle. Soluble organics are rapidly decomposed while solids that are not readily treated settle in the digester and are decomposed over a longer period. Treated effluent is decanted off of the top of the digester and excess sludge is wasted from the bottom of the digester. The batch process is then repeated.

ASBR technology takes advantage of high microbial concentration for rapid decomposition of solubles and retention of solids for later decomposition. The process requires significant equipment and process control. At this time, full scale use of this technology has not been demonstrated on farms in the United States and therefore will not be considered further.

High Solids Digester

High solids digestion of animal manures has not been demonstrated. High solids digestion at 18 - 35% total solids has been developed for sorted municipal solid waste (MSW) only. Flow through and batch systems have been built for MSW in the US and Europe, principally for volume reduction rather than energy recovery. The systems are complex and expensive. Tipping fees offset the high capital and materials handling costs.

These designs may be adaptable for cattle manure, however the rheological properties of manure are quite different than MSW. At concentrations above 14% total solids, cow manure cannot be pumped with conventional pumps. At concentrations higher than 25% total solids, cow manure does not contain free water and liquid recycle is not possible. It is possible that a continuous feed digester could be developed, however there are no known pilot studies and batch operation of several digesters is beyond the ability of a typical farm. Therefore, high solids digestion will not be considered further.

Summary - Anaerobic Digester Technology

Ambient temperature covered lagoon, plug flow digester and complete mix digester technologies are known, demonstrated and available for digestion of livestock manure in California and will be considered further in this report.

Attached growth systems are common for dilute soluble wastes not typical of manures. ASBR and high solids technology are experimental at this time. None of these three systems have been commercially demonstrated using livestock waste and so will not be considered further in this report.

California Animal Rearing Practices that Impact Anaerobic Digestion

Key Factors in Manure Production and Collection

The following terms and concepts are used in throughout this section and are defined here for the reader.

Manure Production. A digester design is based on the maximum *foreseeable* weight of animals producing manure. Manure properties are discussed in terms of " animal units" which equal 1000 pounds of live animal. The daily manure volume is calculated based on the live animal weight of the ultimate animal population using solids yield numbers " as excreted" from the USDA SCS Agricultural Waste Management Field Handbook (1992 ed.), Chapter 4. Please note: The American Society of Agricultural Engineers publishes Standards, containing ASAE Data: ASAE D384.1 " Manure Production and Characteristics" where projected manure yields are higher and probably a better estimation tool for California.

Digestible, Collectible Manure. A digester is designed based on the per cent of the total daily manure production that can be collected daily to weekly without contamination such as dirt, rocks, branches or large amounts of straw.

Process Water. Process water flows into the manure management system and must be included in all digester design analysis. Process water may include but is not limited to: fresh or recycled flush water, hose wash water, sprinkler wash water, animal cooling water, machine cooling water, machine cleaning water, nipple water wastage, bowl or trough water wastage and leaky pipes.

Identification of Target Animal Production Facilities

An anaerobic digester requires daily manure feed to produce a consistent level of biogas. Different types of animal production are briefly discussed to identify the potential for methane production. Dairy and hog production facilities are the most likely candidates for anaerobic digesters in California.

Dairy Farms

Dairy farms generally confine cows and manage manure regularly as described in Chapter 4 and Appendix A. At least 12 digesters have been built on California dairies with varying levels of success.

Hog Farms

Hog producers in California generally collect manure daily with either flush collection or hose wash pen cleaning. Methane production is possible. One owner is recovering methane from 3 different lagoons at 3 different farms.

Egg Producers

Most egg producers would not be able to benefit from methane production because manure in modern " high rise" egg ranches is only cleaned out semi-annually. Older " flat houses" could successfully produce methane because manure is recovered regularly. However, methane production requires 2:1 dilution with water. Many egg producers do not own adequate land for manure management, therefore, the cost of hauling 3 times the normal volume of material offsite is, in most cases, prohibitive. Hauling to a remote digester unit would be possible if the remote unit had a use for electricity and adequate land for nutrient management. One layer manure digester was built in California. The digester operated well for 3 years but was taken out of service when the buyback price of electricity was reduced to below the cost of production.

Broiler and Turkey Producers

Broilers and turkeys are raised on litter (sawdust or rice hulls) and producers collect the manure-litter mix every 9 - 36 weeks. The irregular collection of manure and dilution with undigestible material precludes anaerobic digestion of broiler manure.

Beef Cattle

Beef animals are kept on pasture where manure is not collected until they are large enough for finish feeding. Most beef cattle finish feeding occurs in large dry lots with infrequent manure collection. Due to infrequent collection, the manure is often mixed with sand and rocks and is generally unsuitable for methane production.

Summary - Target Animal Types

The target farm types for this report are dairy and hog farms where manure from animals is recovered regularly.

Animal Production Facilities in California and the Effect on Anaerobic Digester Opportunities

The amount of manure that can be collected, collection interval and collection technique determine the anaerobic digestion technology that could be used.

Dairies

The state was divided into dairy regions in Chapter 4. These are climatic and management groupings. Rainfall increases from south to north determining the most appropriate dairy facilities, manure collection and manure management. California dairies tend to manage their animals in very similar ways regionally, regardless of the number of animals. Feed formulation and milking practices are typically similar within the regions.

Significant Dairy Waste Management Practices Affecting Manure Collection

All Regions - Process Water Generation from Milking Parlor

Process water from the milking parlor is the largest source of new liquids reaching the manure management system. As most of the milking barns in a region have similar in equipment, they are probably similar in wastewater production, though certain farms may use significantly more water.

Distribution of Dairy Types

The most notable differences between dairy regions are in cow housing and manure management. Manure management is relatively similar in similar cow housing. Therefore, the dairies are grouped into " dairy types" based upon cow housing and manure collection. Previous studies, reported in Chapter 4 and Appendix A, grouped dairies into three types based on CFDA reporting. However, the drylot category can be divided into " freestall scrape" and " drylot" because daily freestall scrape systems, not differentiated by CFDA, can use plug flow digesters. Therefore, four dairy types defined here for later use in modeling are:

1) Freestall Flush
2) Drylot with Feedlane Flush
3) Freestall Scrape
4) Drylot

The estimated distribution of dairy types among significant dairy regions is presented in Table 5.2.

Table 5.2 Distribution of Dairy Types

Dairy Type	Southern	South Valley	North Valley	Coast and Northern
Freestall Flush	2%	25%	26%	40%
Flushed Feedlane	4%	60%	17%	6%
Freestall Scrape	16%	6%	52%	39%
Drylot	78%	9%	4%	15%

Effect of Dairy Manure Handling on Methane Production

This section matches digestion technologies with manure collection techniques.

Flush Collected Manure and Parlor Waste and Process Water

Manure that is collected by flush removal is diluted to less than 2% total solids. Solids separators are often used to keep solids from building up in the lagoon. Due to dilution, a covered lagoon digester is the only available anaerobic digestion technology.

Scrape Collected Manure

Dairy manure that is scrape collected regularly and not diluted with parlor washwater can be digested in a plug flow digester. If parlor washwater is added, the mixture can be digested in a complete mix digester.

Table 5.3 shows typical manure collection intervals for scrape dairy types. Scrape manure does not lose much biogas production potential during the first week after deposition. Manure begins to significantly decompose after two weeks and is probably not worth collecting for digestion after 4 weeks.

Table 5.3 Typical Scrape Dairy Manure Collection Intervals

Dairy Type	Collection Interval
Scrape Freestall Dairy.	daily to weekly
Drylot Dairy - Feedlane Manure	daily to weekly
Drylot Dairy - Drylot Manure	1 - 3 times/year

The potential for use of dry lot manure depends upon the operator, the dairy layout and ability of a machine operator to collect only manure from the drylot surface. Arizona Dairy Company of Higley, AZ, operated a digester with scraped dry lot manure for many years. Manure was collected, mixed with water and pumped into a plug flow digester. Individual pens were only scraped about once a month.

Hog Farms

The majority of hogs in California are located in the southern San Joaquin Valley at a few farms. Small hog production facilities are scattered throughout the state. Hogs are generally housed in barns. Some smaller operators house hogs outside in pens or in covered pens.

Manure Collection

Manure is usually recovered from hog buildings using recycle flush systems. Barns are flushed 2 - 6 times per day. Small farms may use a daily hose wash to remove manure. In general, 100% of the hog manure is recovered daily in flush liquids. Hog farms generally do not use solids separators to keep solids from building up in the main lagoon because most of the solids will decompose.

Process Water Use

Most hog farms spend several days a week washing buildings for sanitation purposes. Water sprays or misters are often used for hog cooling and may contribute process water. Hogs waste water when drinking from or playing with hog waterers. These practices contribute wastewater to the collection system.

Effect of Hog Manure Handling on Methane Production

Flush collection dilutes fresh manure but delivers fresh volatile solids daily to a lagoon. If all manure is collected daily, then there is no loss of digestible volatile solids.

Summary- Anaerobic Digester Technologies for Various California Farm Types

Table 5.4 matches digestion technology with farm type and manure collection technique.

Table 5.4 Digester Suitability for California Animal Manures

Solids Content **Waste Collection**	12% *Scrape dairy*	2 - 10% *Mixed dairy scrape and washwater*	< 2% *Flushed dairy or hog, dairy washwater*
Ambient temperature covered lagoon	no	no	yes
Complete mix	no	yes	no
Plug flow	yes	no	no

Estimating Biogas Production from Fresh Animal Manure

Biogas production results from conversion of proteins, carbohydrates and hemi-cellulose in the waste. These constituents are generally measured as volatile solids. Animal diet affects volatile solids content and biogas potential. Volatile solids concentration is used to estimate biogas production.

Dairy feed quality is extremely variable and results in variation in milk production. The level of milk production can be used to infer feed quality and biogas production. Table 5.5 provides estimates of biogas production based on levels of milk production assuming 100% manure collection.

Hogs are fed a very consistent ration to optimize weight gain, therefore biogas production shown in Table 5.5 does not vary dramatically between farms. The biogas yields are in term of cubic feet of biogas per animal unit per day (ft^3/AU/d) where biogas contains 60% methane (600 BTU/ft^3).

Biogas production rates listed in Table 5.5 can be used to estimate the maximum output from a properly designed covered lagoon. However, biogas output from a lagoon varies with the ambient temperature. Winter biogas output may be as low as half of the summer output.

Table 5.5 Biogas Production Assuming 100% Manure Collection

Animal Type	Rolling Herd Average 305 day (lbs/cow/305 d)	Biogas Production ft3/AU/d ((@ 60% methane)
Hog	not applicable	36.0
Dairy	17,000 - 19,000	39.3
Dairy	19,000 - 21,000	42.9
Dairy	21,000 +	46.4

Recovery of Solids for Byproducts

Typical mechanical separators recover 15-20% of the solids from manure, while gravity separation may recover up to 40% of the solids.

Ruminant or hog manure solids recovered prior to the digester have very low value. If properly composted these materials may be sold or in the case of ruminant manure, used as bedding. Most of the ruminant manure and hog manure solids passing through a separator will digest in a covered lagoon, leaving no valuable recoverable byproduct.

Digested solids from ruminant manure can be a valuable byproduct. They may be used on farm as bedding or as roughage in heifer or growing stock feed. They may be sold with or without supplemental composting as a soil amendment to nurseries or commercial bagging operations.

Technical Characterization - Anaerobic Digestion Technologies

This section presents detailed information and some of the design considerations of the three anaerobic digester technologies available for farms in California.

General - Anaerobic Digester Planning, Safety and Regulatory Considerations

Planning Considerations. The major considerations in planning a digester are proper size of the system and proper location of components. The future animal population of the operation should be adequately addressed. A lack of adequate treatment and storage capacity or land for nutrient application could limit the future expansion of the operation. Access for operation and maintenance are critical design issues.

Location. The digester should be accessible and serviceable and located as near the source of manure as practicable. Ideally, the digester and energy utilization equipment should be located in an area of the farm frequented by farm personnel. Short runs of buried pipes are preferable. Manure-contaminated runoff should bypass the digester and flow by gravity, if possible, to the effluent storage structure. Uncontaminated runoff should not enter any part of the system. Location should consider slope, distance of manure transmission, vehicle access, wind direction, neighboring dwellings, proximity of streams and floodplains. Vegetative screens or other methods may be used to shield the system from public view and to improve visual conditions.

Safety Considerations. If a digester and methane recovery system will create a safety hazard they should be fenced and warning signs posted to prevent children and others from using it for purposes other than intended. No smoking signs and confined space entry warnings should be posted. Any embankment and surrounding area should be vegetated to control erosion.

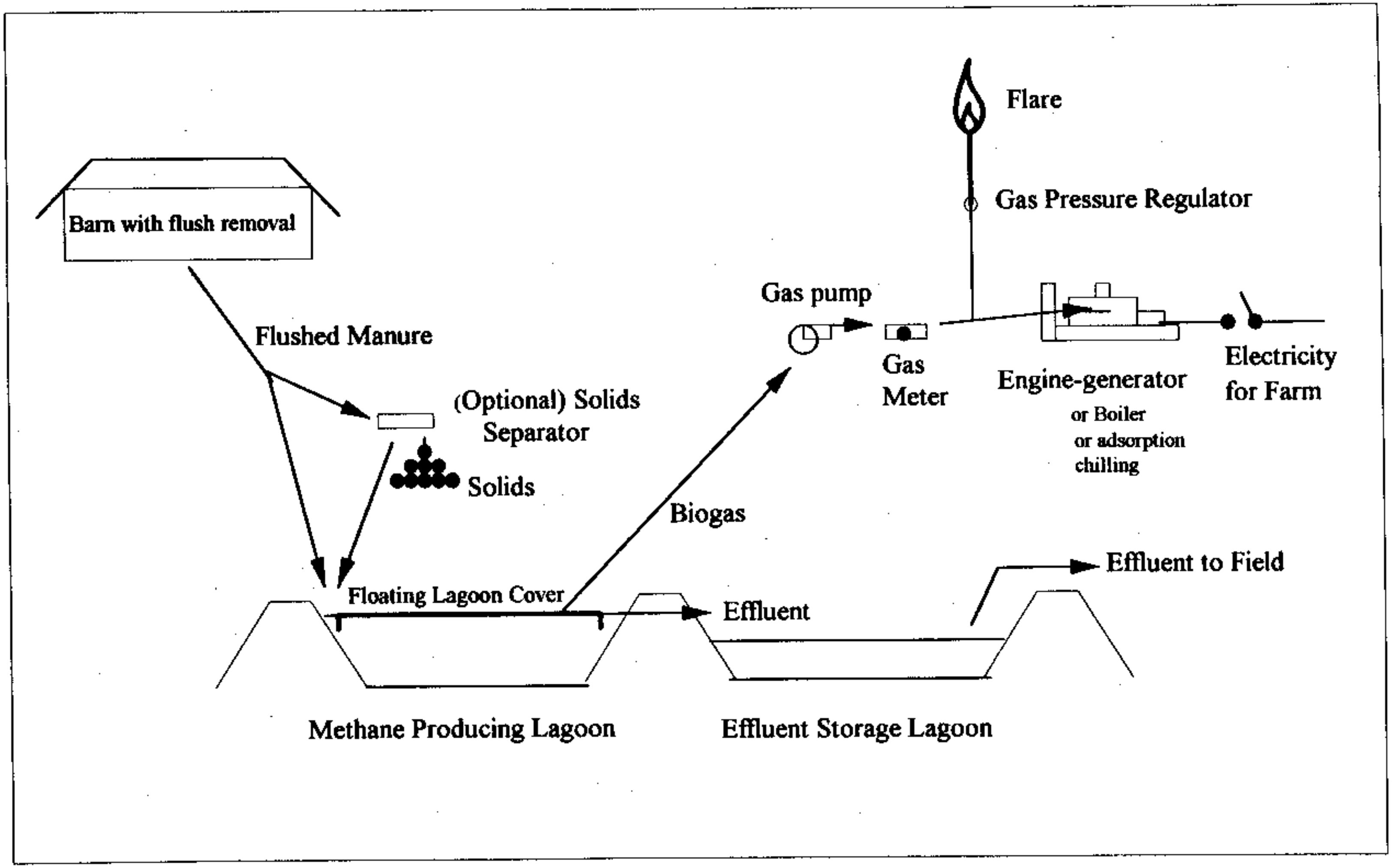
Safety Considerations for Biogas. The major components of biogas are methane (CH_4) and carbon dioxide (CO_2). Another component of concern is hydrogen sulfide (H_2S). Biogas, like " manure gas" , can be toxic if inhaled directly, corrosive to equipment and potentially explosive in confined space when mixed with air. Biogas is as safe as any other fuel such as propane when properly managed on the farm. If improperly managed, these gases can be very hazardous, as has been shown in a number of " manure gas" incidents which injured or killed farmers. See Appendix D for discussion of biogas safety.

Covered Lagoon Digester

Description

A cover can be floated on the surface of a properly sized anaerobic lagoon receiving flush manure to recover methane. The most successful arrangement includes two lagoons connected in series to separate biological treatment for biogas production and storage for land application. A variable volume one cell lagoon designed for both treatment and storage may be covered for biogas recovery. However, a single cell lagoon cover presents design challenges not found in constant volume lagoons and will require assistance of professionals familiar with the design, construction and operation of these systems. Figure 5.2 shows the components of a covered lagoon digester.

Figure 5.2 Covered Lagoon System Components



The primary lagoon is anaerobic and operated at a constant volume to maximize biological treatment, methane production, and odor control. The biogas recovery cover is floated on the primary lagoon. Ideally, manure contaminated runoff is bypassed to the secondary lagoon. The secondary lagoon is planned as a variable volume storage to receive effluent from the primary lagoon and contaminated runoff to be stored and used for irrigation, recycle flushing, or other purposes.

Temperature is a key factor in planning a covered lagoon. Warm climates require smaller lagoons and have less variation in seasonal gas production. Colder temperatures in northern California will reduce winter methane production. To compensate for reduced temperatures, loading rates are decreased and HRT is increased. A larger lagoon requires a larger, more costly cover than a smaller lagoon in a warmer climate. Reduced methane yield may decrease the return on investment.

Components

Solids Separator (dairies only). A gravity solids trap or mechanical separator should be provided between the manure sources and the lagoon.

Lagoons. Two lagoons are preferred; a primary anaerobic waste treatment lagoon and a secondary waste storage lagoon.

Floating Lagoon Cover. The most effective methane recovery system is a floating cover over all or part of the primary lagoon.

Biogas Utilization System. The recovered biogas can be used to produce space heat, hot water, cooling, or electricity. (See Chapter 6)

Covered Lagoon Design Variables

Soil and Foundation. Locate the lagoons on soils of slow to moderate permeability or on soils that can seal through sedimentation and biological action. Avoid gravelly soils and shallow soils over fractured or cavernous rock.

Depth. The primary lagoon should be dug where soil and geological conditions allow it to be as deep as possible. Depth is important in proper operation of the primary lagoon and of lesser importance in the secondary lagoon. Deep lagoons help maintain temperatures that promote bacterial growth. Increased depth allows a smaller surface area to minimize rainfall and to cover size, which reduces floating cover costs. The minimum depth of liquid in the primary lagoon should be 12 ft.

Loading Rate, Hydraulic Retention Time and Sizing of Primary Lagoon. The primary anaerobic lagoon is sized as the larger of volatile solids loading rate (VSLR) or a minimum hydraulic retention time (HRT). The VSLR is a design number, based primarily on climate, used to size the lagoon to allow adequate time for bacteria in the lagoon to decompose manure.

Volatile Solids Loading Rate. Figure 5.3 shows isopleths for the appropriate loading rates for a constant volume primary lagoon in a two cell lagoon system. The figure is from *USDA-Natural Resources Conservation Service Interim Practice Standard, Covered Anaerobic Lagoon, (No.) Code 360*, 1996.

Minimum Hydraulic Retention Time. The VSLR procedure is appropriate in most cases, however modern farms using large volumes of process water may circulate liquids through a primary lagoon faster than bacteria can decompose it. To avoid this washout, a minimum hydraulic retention time (MINHRT) is used to size the lagoon. Figure 5.4 shows MINHRT isopleths. The figure is from *USDA-Natural Resources Conservation Service Interim Practice Standard, Covered Anaerobic Lagoon, (No.) Code 360*, 1996.

Figure 5.3 Covered Anaerobic Lagoon Maximum Loading Rate (lb VS/1000ft^3/day) (NRCS Code 360, Reference 3)

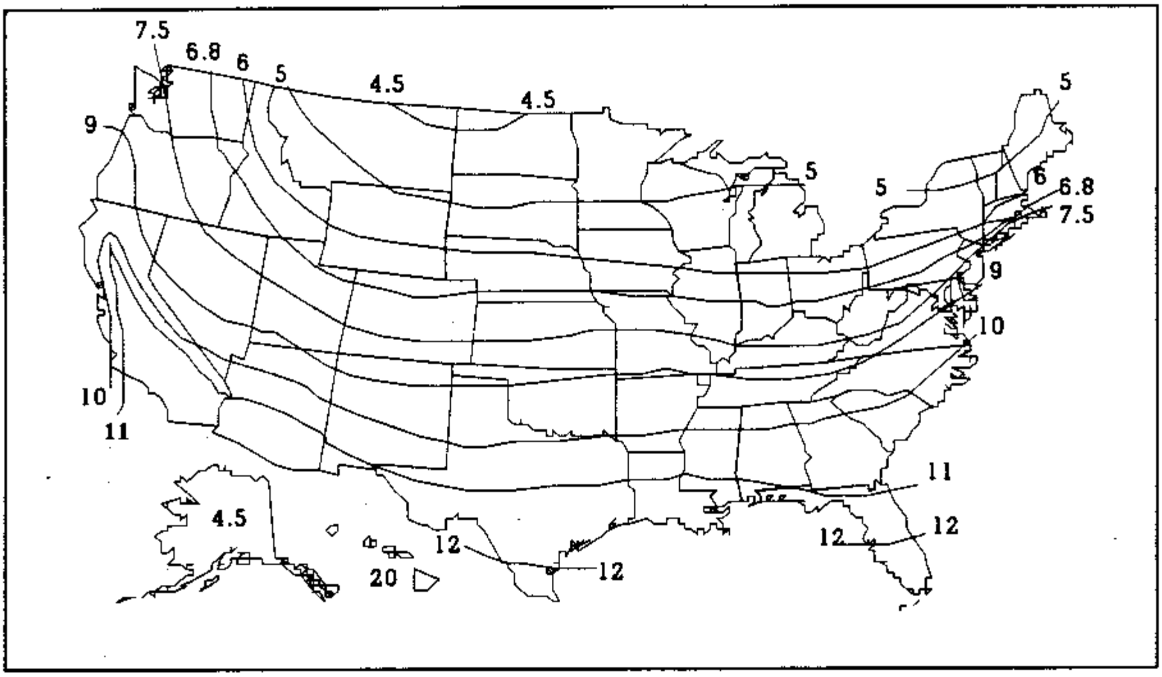
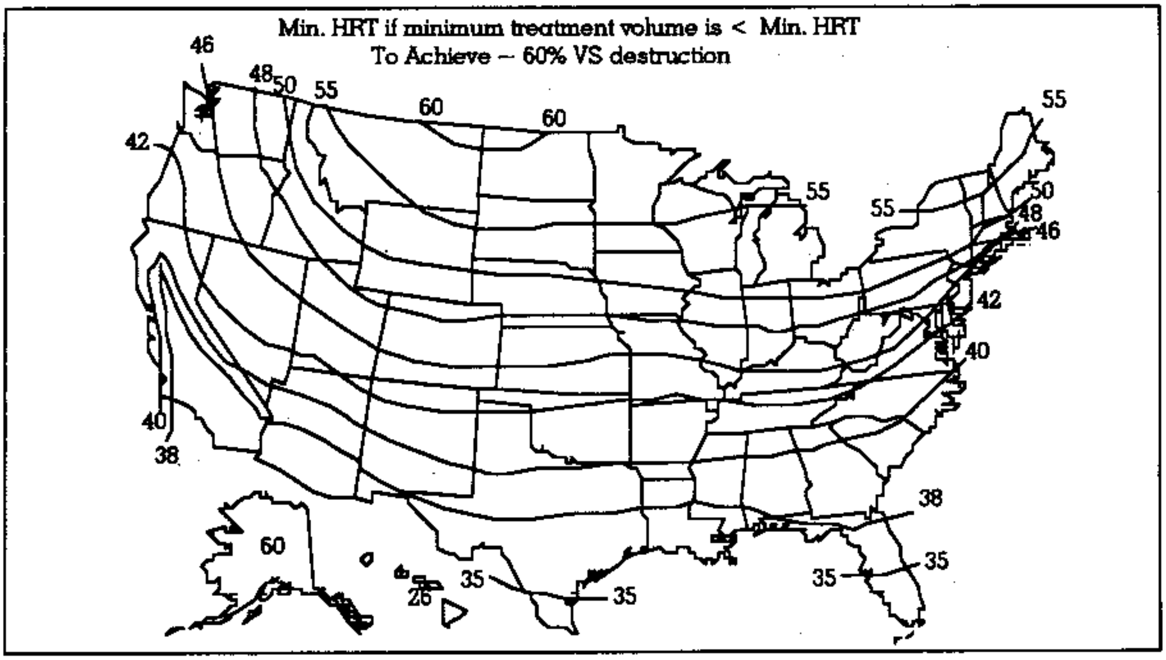


Figure 5.4 Covered Anaerobic Lagoon Minimum Hydraulic Retention Times (NRCS Code 360, Reference 3)



Primary Lagoon Inlet and Outlet. The primary lagoon inlet and outlet should be located to maximize the distance across the lagoon between them.

Rainfall. Rainfall is not a major factor in determining the potential success of a covered lagoon. In areas of high rainfall, a lagoon cover can be used to collect clean rain falling on the cover and pump it off to a field. In areas of low rainfall, a lagoon cover will limit evaporation and loss of potentially valuable nutrient rich water.

Cover Materials. Many types of materials have been used to cover agricultural and industrial lagoons. Floating covers are generally not limited in dimension. A floating cover allows for some gas storage. Cover materials must be: UV resistant; hydrophobic; tear and puncture resistant; non-toxic to bacteria; and have a bulk density near that of water. Availability of material, serviceability and cost are factors to be considered when choosing a cover material. Thin materials are generally less expensive but may not have the demonstrated or guaranteed life of thicker materials. Fabric reinforced materials may be stronger than unreinforced materials, but material thickness selected, serviceability, cost and expected life may offset lack of reinforcement.

Cover Installation Techniques. A lagoon cover can be installed in a variety of ways depending upon site conditions. Table 5.6 lists features found in floating methane recovery lagoon covers. Figure 5.5 shows typical features of lagoon covers.

Full Perimeter Attachment. The entire lagoon surface is covered and the edges of the material are all attached to the embankment.

Completely Floating or Partially Attached Cover. The cover may be secured on the embankment on one to three sides or the whole cover can float within the lagoon. All or some of the sides may stop on the lagoon surface rather than continuing up the embankment.

Operation and Maintenance

The operation and maintenance of a covered lagoon should be relatively simple.

Primary Lagoon - Operation. The proper design and construction of a primary lagoon leads to a biologically active lagoon that should perform year round for decades. Any change in operation will most likely be due to a change in farm operation resulting in an altered volatile solids loading or hydraulic load to the lagoon. The owner should make a visual inspection of lagoon level weekly.

Primary Lagoon - Maintenance. Minimal maintenance of the primary lagoon is expected if the design volatile solids and hydraulic loading rates are not changed. Lagoon banks should be kept free of trees and rodents that may cause embankment failure. Weeds and cover crops should be cut to reduce habitat for insects and rodents. Occasional plugging of inlet and outlets can be expected. Sludge accumulation may require sludge removal every 8 to 15 years. Sludge can be removed by agitating and pumping the lagoon or by draining and scraping the lagoon bottom.

Cover Operation. Operating a lagoon cover requires removing the collected biogas from below the cover regularly or continuously. Large bubbles should not be allowed to collect. If the cover is designed to accumulate rainfall for pumpoff, accumulated rainwater should be pumped off.

Cover Maintenance. The cover should be visually inspected weekly for rainwater accumulation, tearing, wear, and proper tensioning of attachment ropes. The rainwater pumpoff system should be checked after rainfall and maintained as needed.

Figure 5.5 Typical Features of Lagoon Covers

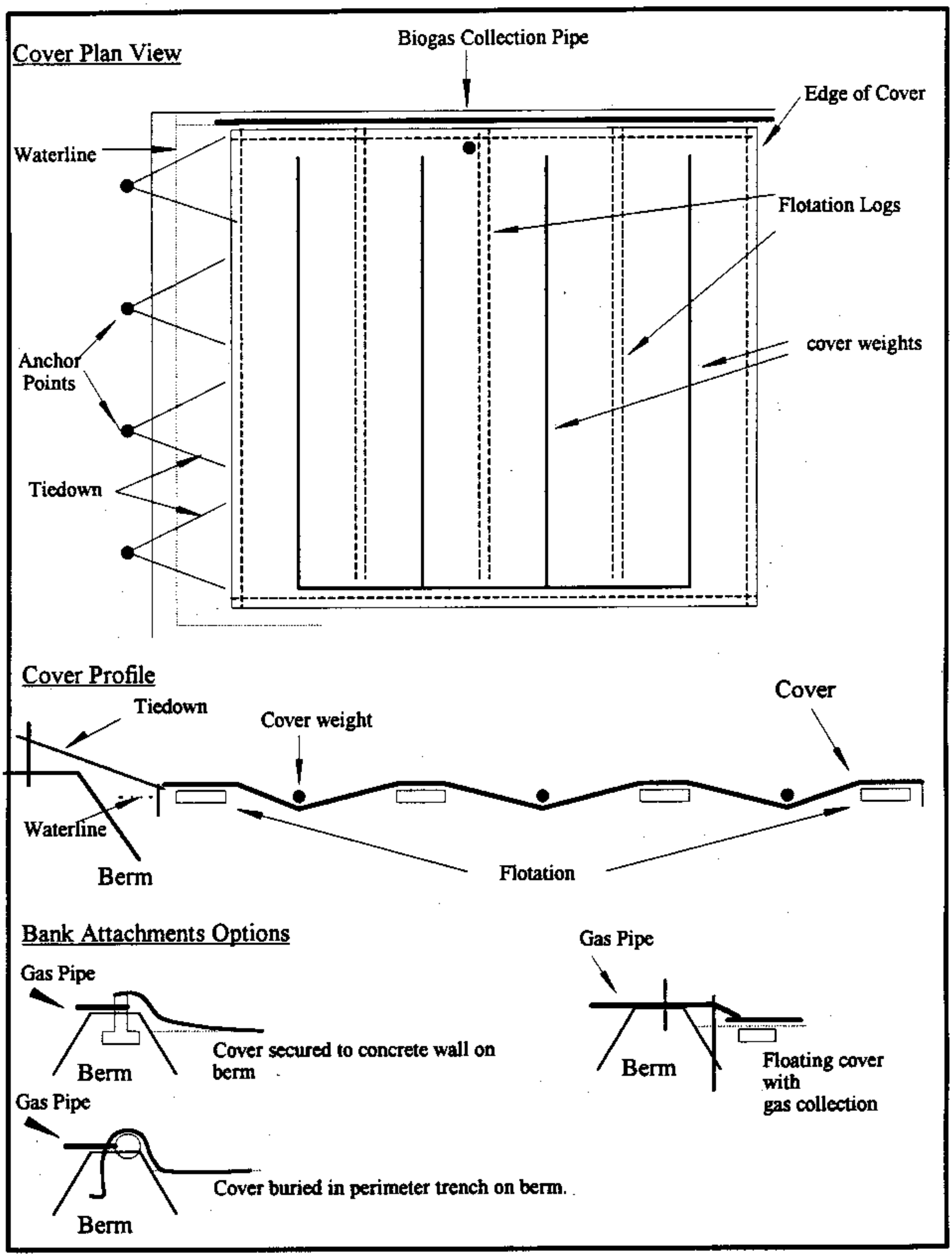


Table 5.6 Features of a Floating Methane Recovery Lagoon Cover

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Bank Attachment Options - See text and Figure 5.5

Rainfall Management - Rainfall may be pumped off the cover or drained into the lagoon.

Securing Edges of a Floating Cover - The edges of the cover can be buried in a perimeter trench on the lagoon embankment or attached to a concrete wall. Floating edges not secured directly on the embankment need support in place. A corrosion resistant rope or cable is attached to the cover as a tiedown and tied to an anchor point.

Skirting - Portions of the cover floating in the lagoon require a perimeter skirt hanging into the lagoon from the cover.

Anchor Points - Anchor points for cable or rope may be driven metal stakes or treated wood posts.

Float Logs - A grid of flotation logs is attached to the underside of the cover. The float logs may be necessary as gas collection channels, to minimize gas pockets and bubbles under the cover.

Weight Pipes - A grid of weight pipes may be laid on the cover surface to help hold the cover down.

Gas Collection - Biogas bubbles to the surface of the lagoon and migrates across the underside of the cover. A gas pump maintains a vacuum under the cover. A gas collection manifold is attached to the cover. A gastight through-the-cover, through-the-attachment wall or under the buried cover gas pipe carries biogas to a biogas utilization system.

Complete Mix Digester

Description

A complete mix digester is a controlled temperature, constant volume, mechanically mixed, biological treatment unit that anaerobically decomposes medium concentration (3-10% solids) animal manures and produces biogas (60% methane and 40% carbon dioxide) and biologically stabilized effluent. Figure 5.5 includes general features of a complete mix digester system.

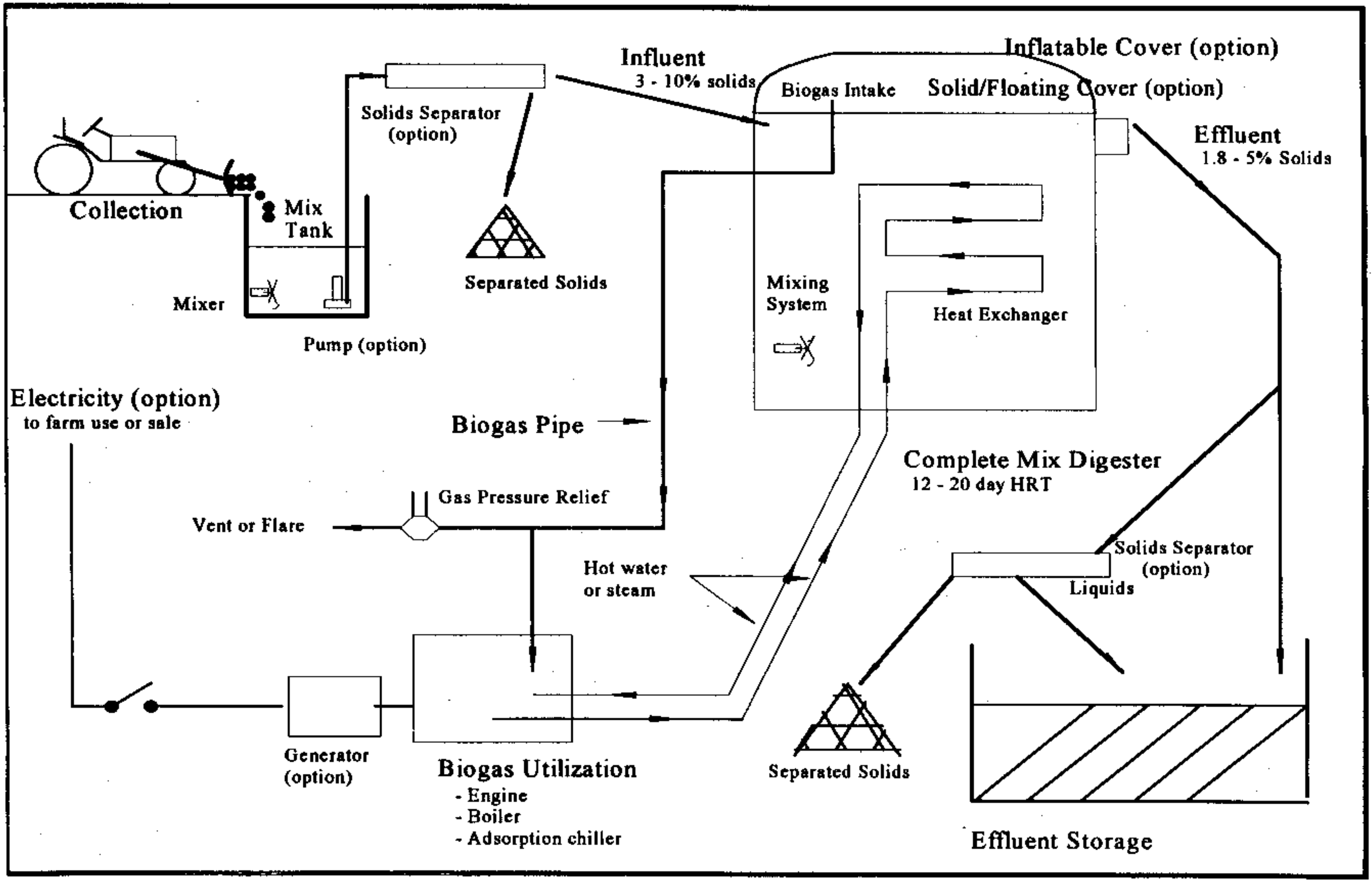
A complete mix digester is designed to maximize biogas production as an energy source. The optimized anaerobic process results in biological stabilization of the effluent and odor control. The process is part of manure management system and supplemental effluent storage is usually required. Manure contaminated rainfall runoff or excess process water should not be introduced into the complete mix digester.

Components

The components of a complete mix digester system generally include a mix tank, a digester tank with mixing, heating and biogas recovery systems, an effluent storage structure, and a biogas utilization system. Pre or post digester solids separation is optional.

Mix Tank. The mix tank is a concrete or metal structure where manure is deposited by a manure collection system. It serves as a control point where water can be added to dry manure or dry manure can be added to dilute manure. Manure is mixed to 3 - 10% solids content prior to introduction into the complete mix digester.

Figure 5.6 Components of Complete Mix Digester



Pretreatment. A solids separator may be used to separate solids from influent manure to reduce solids buildup in the digester.

Complete Mix Digester. A complete mix digester is a heated, insulated above ground or in-ground circular, square or rectangular tank with a mixing system. The tank is covered by a fixed solid top, a flexible inflatable top or a floating cover to collect and direct biogas to the gas utilization system. All covers are gas tight.

Biogas Use. The recovered biogas can be used to produce space heat, hot water, cooling, or electricity. (See Chapter 6)

Solids Separator (Optional): A mechanical separator may be installed after a complete mix digester to capture fibrous materials fed as roughage to ruminants.

Design Criteria

Location: A complete mix digester can be located within a 600 ft radius of the mix tank at a convenient location with good access.

Optimum Solids Concentration. The operating range for influent solids concentration in a complete mix digester is 3 - 10% solids. However, 6 - 8% solids is the preferred concentration.

Mix Tank. The mix tank can be round, square or rectangular. A pump may be required to move manure to the digester.

Hydraulic Retention Time and Sizing of Complete Mix Digester. A complete mix digester will function with an HRT from 10 to 80 days. However, an HRT between 12 and 20 days is most commonly used to economically produce 60-75% of the ultimate methane yield

Operating Temperature. A heat exchange system should maintain the daily temperature fluctuation at less than 0.55° C (1° F). Most complete mix digesters operate in the mesophilic range between 35 - 41° C (95° - 105° F). It is possible to operate in the thermophilic range between 57 - 63° C (135 - 145° F) but the digestion process is subject to upset if not closely monitored.

Insulation. A complete mix digester tank may require insulation to control heat loss.

Heat Exchanger. An external heat exchanger or an internal heat exchanger is used to heat and maintain the digesting mixture at the design temperature. Hot water or steam circulated through the heat exchanger is heated using a biogas-fueled boiler or waste heat from a biogas fueled engine-generator.

Construction Materials. The digester tanks can be concrete or metal.

Mixing. Gas or mechanical mixing is used to stir the digester.

Dimensions. The depth can be between 8 and 40 ft depending upon soil conditions and the required tank volume.

Methane Recovery System. A complete mix digester is covered by a gas tight fixed solid top, a flexible top or a floating cover to collect and direct biogas to the gas utilization system.

Solid Cover. A solid cover is constructed to avoid cracking and leaks. Solid covers should resist corrosion. A solid cover allows for minimal gas storage.

Inflatable Cover. A coated fabric is generally used for inflatable covers. An inflatable cover can be designed for some gas storage. Wind protection may be necessary. The cover must have a gas tight seal. These materials are described in the Covered Lagoon Cover section.

Floating Cover. A floating cover is designed to lie flat on the digester surface. See discussion of floating covers in Covered Lagoon section above.

Operation and Maintenance of Complete Mix and Plug Flow Digesters

Operation and maintenance of complete mix and plug flow digesters is very similar and therefore will be discussed together in this section. Proper operation and maintenance of plug flow and complete mix digesters is necessary for successful operation.

Mix Tank - Operation. On a daily or every other day basis, collectible manure is pushed, dragged or dumped into the mix tank. If necessary, dilution water or drier manure is added to the collected manure and mixed to achieve the design total solids mixture. The mixed manure is released via gravity gate or pumped into the digester.

Mix Tank - Maintenance. Mix tank maintenance consists of normal maintenance of pumps and mixers per manufacturers recommendations. The mix tank will require occasional cleaning to remove accumulated sand, gravel, steel and wood.

Complete Mix and Plug Flow Digester - Operation. A complete mix digester is fed hourly to daily, displacing an equal amount of manure from the outlet. A plug flow digester is fed from the mix tank daily or every other day. The digester heating and mixing system should be checked daily to verify operation.

Complete Mix and Plug Flow Digester - Maintenance. The digester temperature should be checked daily. The effluent outlet and digester gas pressure relief should be checked weekly to be sure that they are operating properly. The heat exchanger pump should be lubricated per the manufacturers recommendations. The mixer in a complete mix digester should be lubricated per the manufacturers recommendations. Sludge accumulation may require sludge removal every 8 to 10 years.

Cover - Maintenance. The cover should be visually inspected weekly for rainwater accumulation, cracks, tearing, wear, and tensioning.

Plug Flow Digester

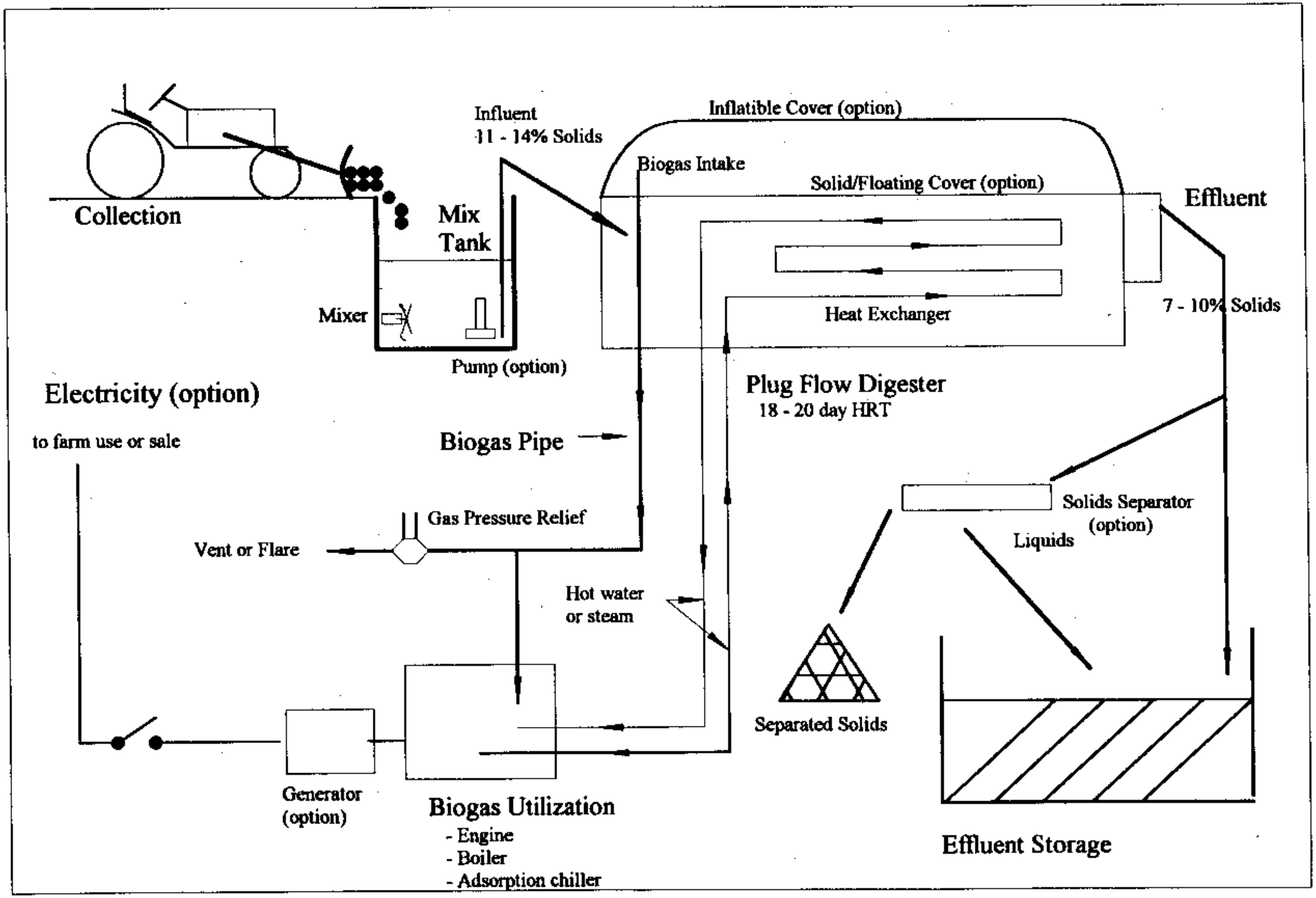
Description

A plug flow digester is used to digest manure from ruminant animals (dairy, beef, sheep) that can be collected as a semi-solid (10-60% solids) daily to weekly with minimal contamination (dirt, gravel, stones, straw) and delivered to a collection point.

Components

A plug flow digester system generally includes a mix tank, a digester tank with heat exchanger and biogas recovery system, an effluent storage structure, and a biogas utilization system. Post digester solids separation is optional. Figure 5.6 showed the features of a plug flow digester system.

Figure 5.7 Features of Plug Flow Digester System



Collection/Mix Tank. A mix tank as described above for a complete digester is used to achieve a solids concentration between 11 and 14% solids.

Plug Flow Digester. A plug flow digester is a heated, in-ground concrete, concrete block or lined rectangular tank. The digester can be covered by a fixed rigid top, a flexible inflatable top or a floating cover to collect and direct biogas to the gas utilization system.

Biogas Utilization System. The recovered biogas can be used to produce space heat, hot water, cooling, or electricity. (See Chapter 6)

Solids Separator (Optional). A mechanical separator may be installed between the plug flow digester outflow and the effluent storage structure.

Design Criteria and Sizing the Plug Flow Digester

Location. If a manure pump is installed to pump the 12% solids manure, the digester can be located within a 300 ft radius of the mix tank at a convenient location with good access.

Mix Tank. The mix tank can be round, square or rectangular. A pump may be required to move manure to the plug flow digester.

Hydraulic Retention Time and Sizing of Plug Flow Digester. A plug flow digester will function with an HRT from 12 to 80 days. However, an HRT between 15 and 20 days is most commonly used to economically produce 70-80% of the ultimate methane yield

Dimensions. The depth of a plug flow digester can be between 8 feet and 16 feet depending upon soil conditions and the required tank volume. The width:depth ratio is usually greater than 1 and less than 2.5. The length:width ratio should be between 3.5 and 5.

Heat Exchanger: An external heat exchanger or an internal heat exchanger is required to maintain the digesting mixture at the design temperature. Hot water circulated through the heat exchanger is heated using biogas as a fuel for a boiler or waste heat from a biogas fueled engine-generator.

Operating Temperature. The daily temperature fluctuation should be less than 1° F. Most plug flow digesters operate in mesophilic range between 95° - 105° F with an optimum of 100° F. It is possible to operate in the thermophilic range between 135 - 145° F, but the digestion process is subject to upset if not closely monitored.

Insulation. A plug flow digester surface may be insulated to control heat loss.

Construction Materials. The digester can be constructed as a lined trench or as a reinforced concrete or block tank.

Methane Recovery System and Covers. See discussion of methane recovery system above under complete mix digesters.

Operation and Maintenance - See Complete Mix Section Above

Economic Characterization - Costs And Benefits

This section will document important components and cost assumptions for the cost/benefit and financial analysis portion of the CMEM model.

Assumptions Regarding Major Cost Elements

Soil and Foundation. It is assumed that the soil is adequate for installing an inground tank or lagoon, allowances are not made for construction costs due to high water tables or plastic clays. Lagoons are assumed to be dug in native material and not lined.

Excavation. Excavation is priced at typical agricultural rates for California.

Tank Construction Material. Mix tanks, plug flow and complete mix digesters are assumed to be constructed of reinforced concrete or concrete block.

Tank Dimensions. Tank dimensions are calculated from the design criteria.

Tank Insulation. All tanks are assumed to be inground or earth bermed. Insulation may be required for above ground tanks but is not included.

Pumps. Manure pumps included in pricing are 20 hp chopper manure pumps, Vaughn or equivalent.

Mixers. Mechanical mixers are priced into all mixing applications, US Agrisystems or equivalent.

Manure and biogas piping. All manure and biogas piping is plastic.

Internal Heat Exchanger. The heat exchanger in heated digesters is assumed to be constructed of steel.

Plug Flow and Complete Mix Digester Gas Collection Cover. The cover is assumed to be a flexible, inflatable cover, Hypalon or equivalent.

Lagoon Cover. Two lagoon cover options are priced. The " high cost" cover is XR-5 or equivalent and the " low cost" option is 20 mill HDPE or equivalent. It is assumed that the material fabricated into partially floating cells with all necessary appurtenances.

Lagoon Cover Bank Attachment System. The lagoon cover is assumed to be tethered to anchor points.

Biogas Pressure Relief. Gas pressure relief is included.

Costs Used in Model

Construction and Component Costs

Table 5.7 shows unit costs used in estimating digester construction.

Digester Operating Costs

Digester operating costs based on existing systems are assumed to be ½ man-hour per day. This factor is adequate to cover real mantime and pump electricity consumption for digester manure handling. This cost is included in the engine-generator operation and maintenance cost function.

Digester Maintenance Costs

Digester maintenance costs have been historically very low, because most of the digester investment is tankage. A maintenance factor of 0.1 % of capital cost is included. This cost is included in the engine-generator operation and maintenance cost function.

Table 5.7 Unit Costs

Note: For Estimation Only, May Not Represent Actual Costs

Soil Test	1200 $/ea	Excavation	1.25 $/yd3
Mantime	120 $/d	Wall Concrete	200 $/yd3
Backhoe	55 $/hr	Flat Concrete	160 $/yd3
Electrician	50 $/hr	Building	16 $/ft2
Plumber	30 $/hr	Cover Elements	
Pipe		Low Cost Cover	0.4 $/ft2
2" PVC	1 $/ft	High Cost Cover	1.45 $/ft2
3" PVC	1.5 $/ft	Appurtenances	0.5 $/ft2
4" PVC	2 $/ft	Gas Flare	400 $/ea
8" PVC	4 $/ft	Berm Wall	6.25 $/ft
1.5" Steel	0.93 $/ft		
2" Steel	1.21 $/ft		
2.5" Steel	1.88 $/ft		
3" Steel	2.43 $/ft		

Engine-Generator Operation and Maintenance Costs

Engine-generator operation and maintenance costs are assumed to be $0.01/kWh including: consumables such as oil and spark plugs and interval maintenance such as valve jobs and overhauls. It is assumed that minor maintenance is performed on farm by farm personnel and interval maintenance is performed by contractors. Digester operation and maintenance costs are included in the engine-generator cost function at $0.005/kWh.

Benefits

An anaerobic digester is installed to return benefits to a farm. The benefits may be monetary or non-monetary.

Monetary Benefits

The monetizable products of a digestion system are:

Energy Production

Electricity. Biogas can be burned in an engine to produce electricity for the farm and offset normal electricity purchases. Excess electricity may be sold to the utility at a relatively low price.

Space Heat. Hot air produced directly from the combustion of biogas or recovered from a biogas fired engine can replace purchased fuel or electricity.

Hot Water. Hot water produced directly from biogas combustion or recovered from a biogas fired engine can replace purchased fuel or electricity.

Digested Dairy Solids for Cow Bedding. Solids can be used to offset purchase of bedding material. However, the value of bedding can only be assigned on a farm by farm basis because each farm has a unique source for and cost of bedding.

Digested Solids Sales. Recovered solids from dairy waste can be sold as soil amendments.

Reduced Lagoon Cleanup Costs. Separation of digested and undigested solids reduces the cleanout interval and costs for cleaning manure storages.

Non-Monetary Benefits

Odor Reduction. Recovery of biogas substantially reduces the offsite loss of odiferous manure gases, thereby limiting complaints and reducing confrontations with neighbors due to manure odors.

Improved Manure Handling. Some digesters save the farm money due to the improved characteristics of digested manure. For example, digested scraped manure is easily pumpable whereas undigested scraped manure may not be pumpable.

Improved Manure and Nutrient Management. Almost all digester installations result in improved manure and nutrient management by the farm due to a greater appreciation of the manure resource.

Reduction in Release of Greenhouse Gases. Methane has been targeted as an important greenhouse gas. Capture and combustion of methane reduces its potential activity in the atmosphere.

California Methane Estimation Model (CMEM)

Introduction

The CMEM model was developed as two models for estimating the costs and benefits of methane production. The models, CECCOW3.XLS and CECPIG3.XLS are spreadsheet programs written in Excel 5.0. To operate the models from Excel 5.0, open the file CECCOW3.XLS for dairy applications and CECPIG3.XLS for pig farm applications. The models cannot be overwritten or unlocked. Your customized workbook can be stored.

The purpose of the models is to give the user a basic analysis of the feasibility of a methane production system including rough costs and benefits. If the answers are favorable, a detailed analysis is warranted. *The models are not design tools*, because every farm has features different from the generalized default values used. *No warranty is expressed or implied as to the accuracy of these models.*

The models require inputs in the sheets *Farm Info* - where you characterize your farm, *Cow Number* or *Pig Number* - where you input animal population and waste management details, and *Decisions* - where you answer questions about the farm and proposed digester. Model inputs are listed in Table 5.8 and an input data collection sheet is included in Appendix E. You must answer all questions to get a usable answer. Defaults are used in some areas that you may overwrite if appropriate for your farm. Table 5.9 lists the uses of the inputs.

The model outputs are displayed on 3 sheets, *System* - a summary of the system for which costs are generated, *QuickEst* - a more detailed presentation of component costs and benefits, and *Financial* - an analysis of the net present value of the system based on assumptions presented in Chapter 6.

Table 5.8 Model Inputs

Animal type	Manure collection technique
Animal number	Manure collection interval
Animal housing	County location
Energy prices	

Table 5.9 Use of Inputs

Estimate amount of manure collected fresh daily
Size and select a digester option for the waste collection technique and expected loading rate
Estimate the gas production of the digester
Estimate the cost of the digester
Estimate the cost of gas use for electricity production
Estimate the benefits of gas use for electricity production
Compare costs and benefits
Present a summary of financial performance measures

References

1. Quok. Linda, et al, " Potential of Biogas Systems for California Farms with Confined Animals", California Energy Commission, 1981
2. Moser, Mark A., " Potential Methane Generation Study of the South Valley of California", Report to Climate Change Division of the Office of Air and Radiation, US EPA, Washington DC July, 1991, unpublished
3. USDA-Natural Resources Conservation Service Interim Practice Standard, Covered Anaerobic Lagoon, (No.) Code 360, 1996.

VI. Biogas Transmission, Handling, and Use

Introduction

This chapter is applicable to biogas storage, transmission, handling, and use from all digester types. It is applicable to biogas utilization up to 90,000 ft^3 per day, the average amount of biogas produced by 100% conversion of the manure from approximately 1,500 dairy cows or 22,500 pigs. Each section is divided into considerations, components, operation and maintenance, and cost factors. Medium (up to 200 psi) and high pressure (>2000 psi) storage of biogas will not be considered due to their technical complexity and high cost.

A more detailed discussion of equipment can be found in The Handbook of Biogas Utilization, published by the Southeastern Regional Biomass Energy Program, Tennessee Valley Authority, Muscle Shoals, Alabama 35660. Individual equipment suppliers should be contracted for equipment performance and specifications.

Considerations

This section includes general considerations applicable to the following sections.

Biogas Production. Biogas is produced by a digester at a steady daily rate. Biogas cannot be cost effectively stored, therefore energy production or use must be relatively constant.

Biogas Flow Rate and Pressure. The maximum biogas flow rate (ft^3/min) with an appropriate safety factor should be used to size all flow related components. Using in-vessel storage, gas pressure is not expected to exceed 0.25 psi.

Selection of Materials. All materials should be corrosion resistant.

Location. Equipment should be located in an area protected from animals or people. The equipment should not be located in unventilated spaces due to the potential for accumulation of gases.

Safety Considerations for Equipment Location. Buried pipes and above ground plastic pipe should be protected from damage. An atmospheric release pressure valve or flare should be located away from any source of ignition or building ventilation intake. Flares should be tall enough to avoid danger to people and livestock. Equipment should be located in buildings or manholes that can be completely ventilated or that are small or shallow enough that a person cannot completely enter the space without removal of a side or lid. Fencing or impact barrier posts may be needed. Confined space entry, no smoking and fire hazard signs should be posted where appropriate. A simple gas detection monitor should be installed in equipment rooms to sound alarm if a biogas leak is detected. See Appendix D.

Biogas Transmission

This section covers biogas collection and in-vessel low pressure (<0.4 psi) storage, transmission piping, pressure relief and condensation from all methane digesters. Biogas handling and use are covered in subsequent sections.

Components

The following components are part of a biogas transmission system and are included as costs in modeling the cost of the system. (see Figure 6.1).

Low Pressure Storage. The digester cover system may be designed to store biogas for a short period of time. Floating or inflatable covers may able to store biogas production at pressures less than 2 inches water column pressure (.07 psi). Properly designed fixed covers may be able to store several hours of gas production at up to 10 inches water column pressure (0.37 psi).

Biogas Intake. The biogas intake is a pipe extending into the biogas collection cover to collect biogas and withdraw it to the biogas transmission system.

Gas Pressure Relief. A pressure relief valve is used to release pressure buildup when biogas is produced faster than it is being used. The pressure relief valve should release excess biogas to a flare. Commercial pressure relief valves are available.

(Optional) Flame Arrester. A flame arrester prevents a flame from burning back down a pipe. Some local building codes may require a flame arrester. Commercial flame arresters are available.

Transmission Pipe. The biogas transmission pipe carries biogas from the methane recovery system to the utilization system. PVC pipe may be used. Some city or county codes may require exposed biogas piping to be either metal or protected from damage. Pipe is usually installed underground and sloped down to a condensate drain with no swales that would accumulate condensate.

Condensate Drain. When biogas enters a pipeline, water vapor condenses on the cooler surfaces and must be drained from the pipe. Condensate drains will be needed at all low points in a biogas transmission pipe. . Commercial condensate drains are available

Flare. A flare is needed to burn off excess biogas. There may be occasional excess biogas production or times when the gas use system is under repair and excess gas must be released. Flaring reduces potential dangers associated with unburned biogas. Commercial flares are available. Automatic ignitors resistant to corrosive gases should be included.

Operation and Maintenance Requirements of Transmission System

Inlet pipe. Inlet operation is relatively minor. Maintenance might consist of occasional unplugging.

Pressure Relief Valve. The operation of the relief valve should be automatic. The valve should be inspected weekly to insure proper function.

Condensate Drains. Condensate drains should operate automatically, but weekly observations should be made.

Flare. The flare should be inspected monthly for proper operation.

Cost Factors

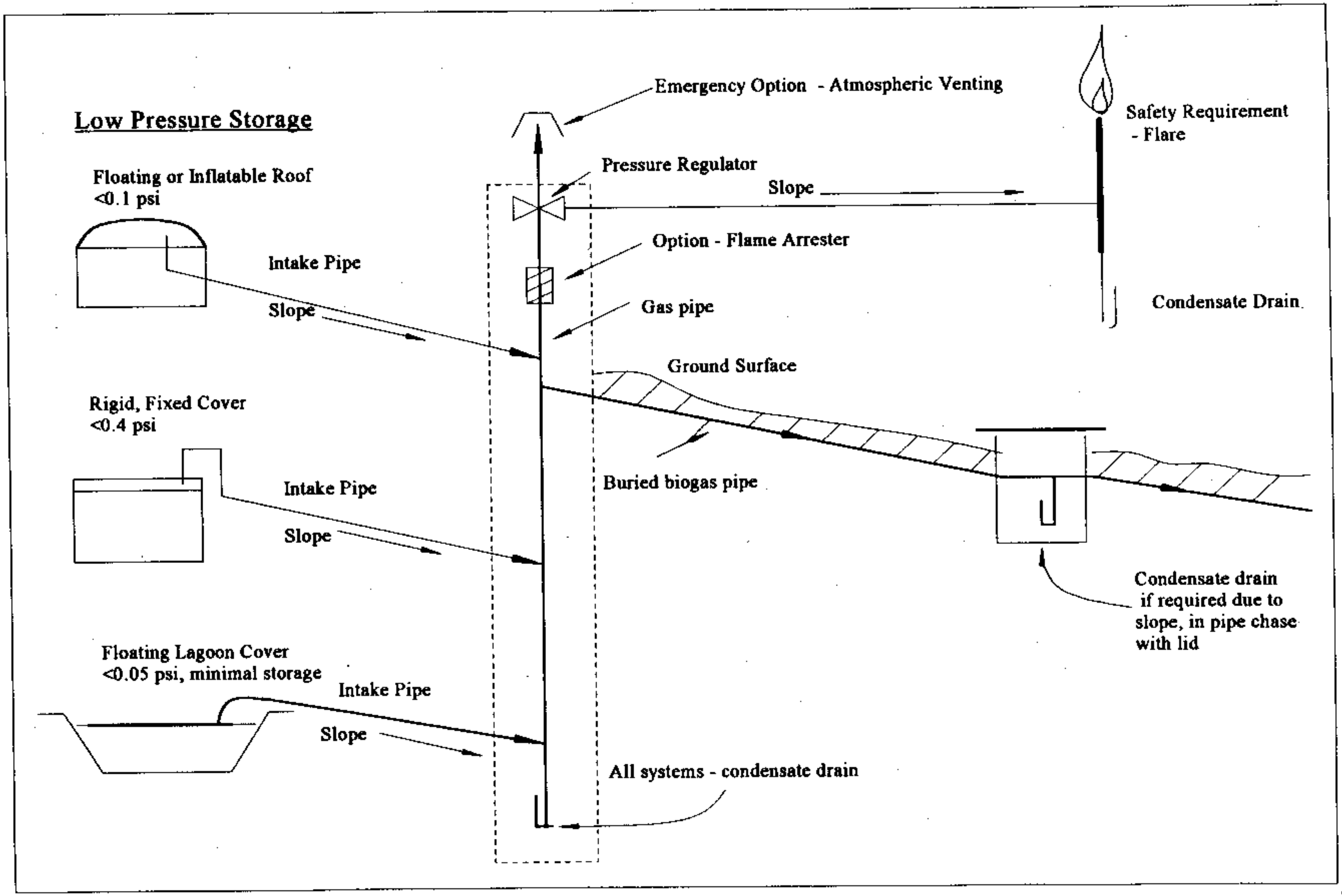
Unit costs are included in Table 5.7.

Model Inputs

The following inputs must be identified and input into the model:

1) distance from digester to gas handling
2) number of manholes and condensate traps

Figure 6.1 Biogas Collection, Storage and Transmission



Biogas Handling

This section covers biogas handling prior to use, assuming low pressure (<0.4 psi) gas treatment, filtration, pressurization, and metering. It is recommended that a competent professional be consulted when planning biogas handling.

Components

Figure 6.2 shows a typical biogas handling system with the components described below. The biogas transmission system is designed to deliver biogas at the system design pressure. The gas use must be identified prior to developing the biogas handling system in order to properly size components.

Gas Filter. All gas streams should have an in-line strainer-screen filter as a minimum to catch debris left in the pipeline during construction.

Gas Treatment (option). Biogas is saturated with water vapor and will contain hydrogen sulfide. Table 6.1 shows ranges of H_2S found in biogas streams. Gas treatment may be needed for specific gas uses where hydrogen sulfide could be corrosive to equipment such as boilers, direct fire room heaters, adsorption chillers and forced air furnaces. For small scale biogas uses, the most cost effective biogas treatment technique is dry chemical oxidation to bind sulfur compounds. Iron sponge, activated carbon, and chemically impregnated filter cartridges can be used to remove inline debris, water vapor and/or hydrogen sulfide.

Gas Pump or Blower. A gas blower or pump is used to increase biogas pressure. The gas blower/pump can be either a vane or lobe type and either belt or direct driven. The gas blower should be made of non-corrosive materials.

Gas Meter. A gas meter is essential to monitor the methane recovery system. The ratio of a daily output (kWh, tons of cooling, BTU's of heat) to daily gas quantity is monitored to assess the status of gas use equipment. Meter components that contact biogas should be corrosion resistant.

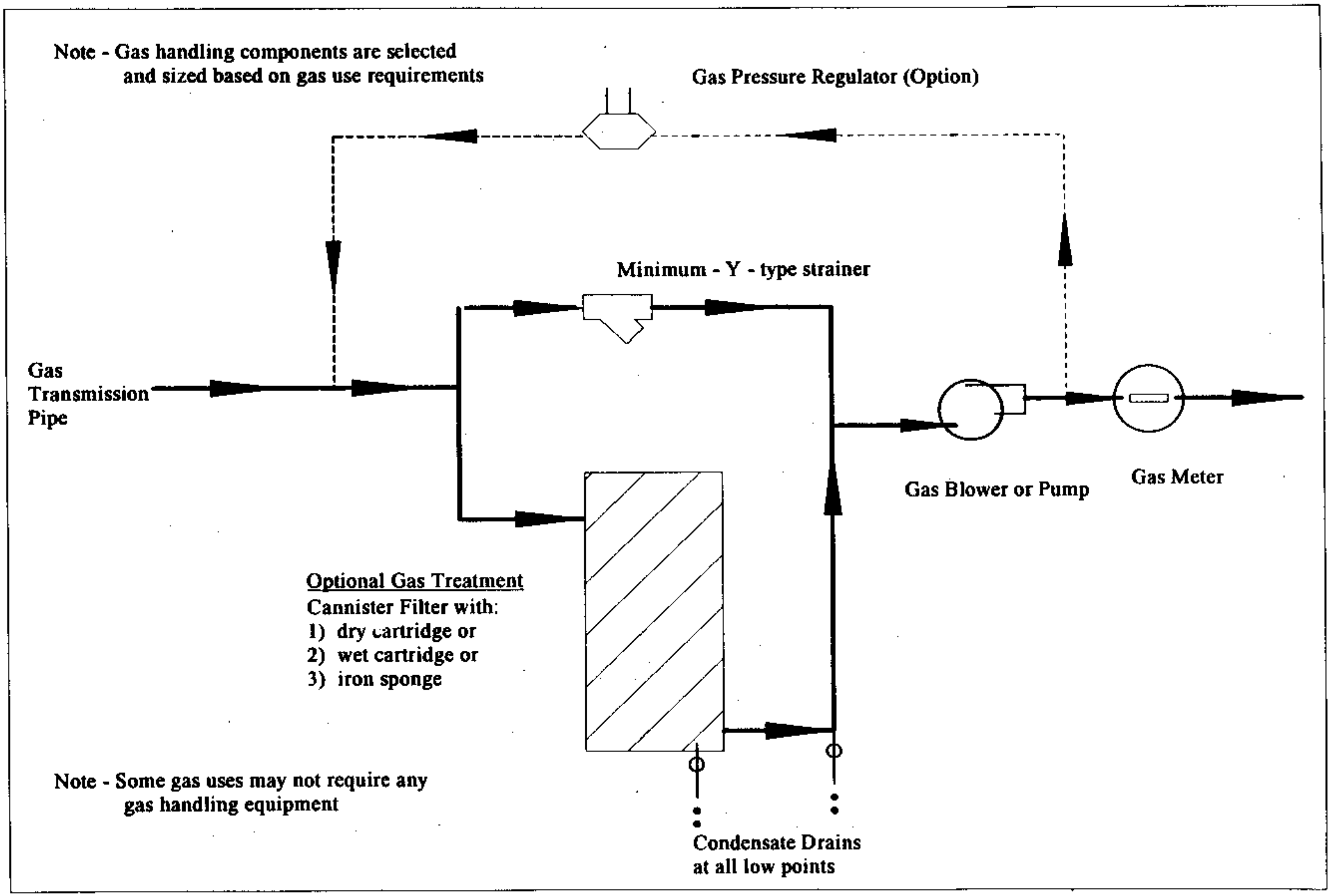
Gas Pressure Regulator (option). A gas pressure regulator is used to relieve excess gas pressure to a flare or back to the beginning of the gas handling system.

Condensate Drain. Condensate drains should be installed at all the low points in the gas piping.

Table 6.1 Ranges of Hydrogen Sulfide found in Biogas from Various Sources

Digester Type	Range of H_2S in Biogas
Covered Lagoon	500 - 2500 PPM
Complete Mix Digester	1800 - 6000 PPM
Plug Flow Digester	1500 - 2800 PPM

Figure 6.2 Components of Gas Handling System



Operation and Maintenance of Gas Handling Equipment

Gas Strainer/Filter. Gas strainer filter should be cleaned after startup and then as required.

Gas Treatment. The designer or manufacturer should supply an operation and maintenance plan for a gas treatment system. Condensate is drained and filter material changed as required.

Gas Blower/Pump. The gas blower should be inspected weekly for leakage and lubricated per manufacturer recommendations.

Gas Meter. The gas meter should be inspected weekly for leakage and lubricated per manufacturer recommendations.

Gas Pressure Regulator. The regulator should be inspected weekly to insure proper function.

Condensate Drains. Manual drains are operated as required on a weekly to monthly basis. Occasional observation should be made of open traps and automatic drains.

Cost Factors

A range of gas flows were selected and each of the components of gas handling were sized to the gas flow rate. Equipment suppliers were contacted and December 1995 pricing was developed for the component equipment. Table 6.2 shows the gas handling component pricing for appropriately sized available equipment.

Operation and Maintenance Costs. Operation and maintenance costs of a gas handling system are relatively minor. An annual allowance for operation and maintenance is included in the estimation of gas use operation and maintenance costs.

Table 6.2 Uninstalled Low Pressure Gas Handling Equipment Costs, December 1995

NOTE: THESE COSTS FOR ESTIMATION ONLY

Gas Output - 600 BTU Gas

Ft3/d	3000	6000	9000	15000	21000	27000	33000
SCFM	2	4	6	10	15	19	23
Gas Pump	$ 574	$ 574	$ 574	$ 574	$ 637	$ 637	$ 1,448
Gas Meter	$ 540	$ 540	$ 540	$ 540	$ 901	$ 901	$ 901
Mercaptan Filter	$ 1,050	$ 1,050	$ 1,050	$ 1,050	$ 1,050	$ 1,100	$ 1,100
Gas Pressure Regulator	$ 40	$ 40	$ 40	$ 65	$ 65	$ 65	$ 90

Ft3/d	39000	45000	52500	60000	75000	90000
SCFM	27	31	36	42	52	63
Gas Pump	$ 1,448	$ 1,798	$ 1,798	$ 1,798	$ 1,798	$ 3,200
Gas Meter	$ 1,419	$ 1,419	$ 1,798	$ 1,798	$ 1,798	$ 2,100
Mercaptan Filter	$ 1,250	$ 1,250	$ 2,500	$ 2,500	$ 2,500	$ 3,750
Gas Pressure Regulator	$ 90	$ 90	$ 125	$ 125	$ 125	$ 175

Model Inputs - Gas Handling

Gas flow is calculated by digester type and used by the model to select components and estimate costs.

Biogas Use

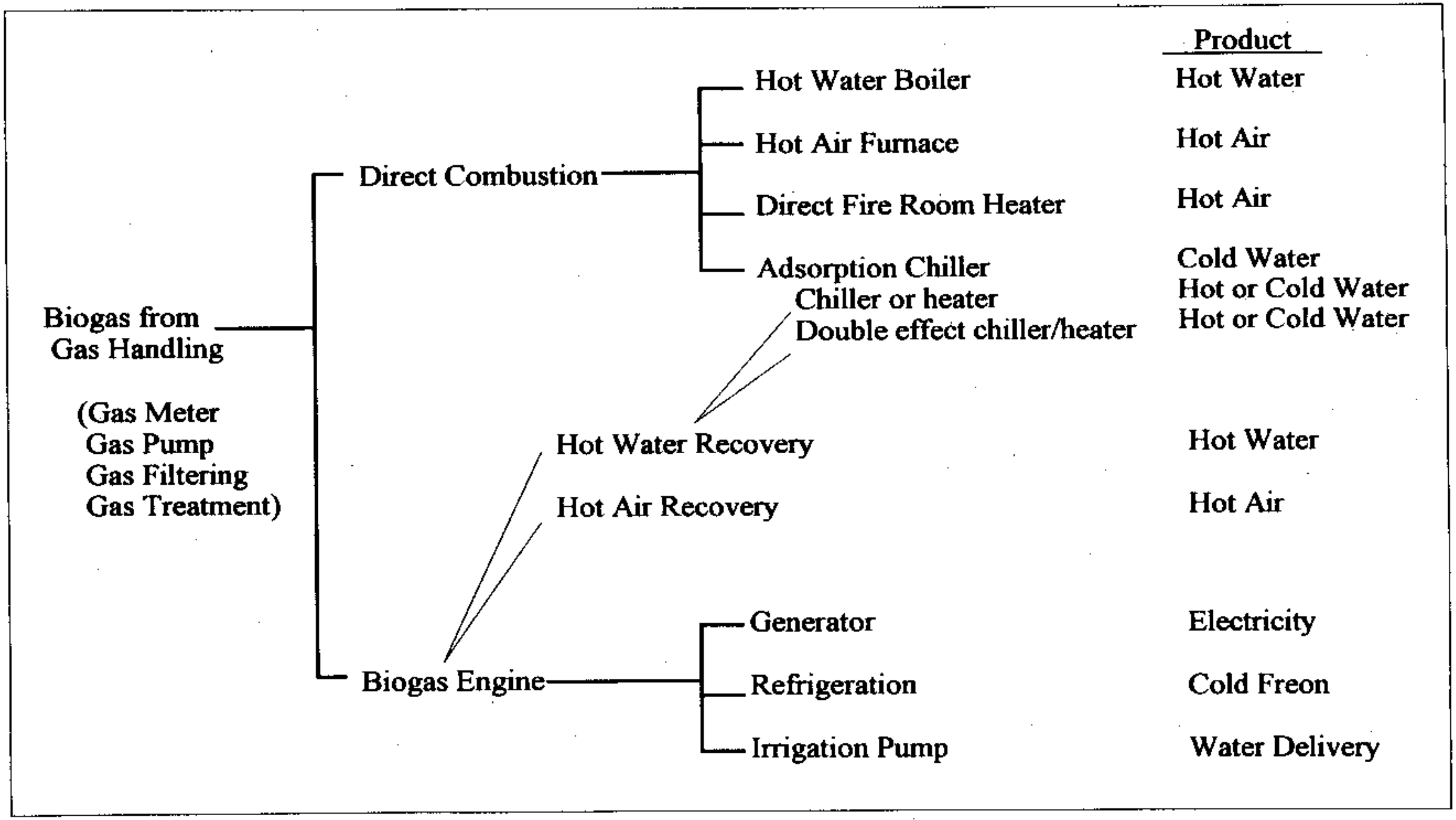
Biogas that is pressurized and metered can be used as fuel for heating, adsorption cooling, electrical generation and cogeneration. Figure 6.3 shows biogas use options. Biogas can be substituted for low pressure natural gas or propane in the equipment listed in Table 6.3 and described later in this section.

This section does not cover medium and high pressure gas systems, steam generation for process steam or steam turbines, direct combustion gas turbines, Sterling engines or fuel cells. These technologies are not currently in use at any farm digesters. These technologies require a greater degree of engineering, installation, and operating skills than normally found in the farm community. Small scale equipment is custom built by a very limited group of suppliers. Service for these units is generally unavailable. These technologies are briefly discussed in Appendix G.

Table 6.3 Biogas Use Options

Biogas Fueled Engine
Electrical generator - electricity for use or sale, heat recovery optional
Refrigeration compressors - cooling, heat recovery optional
Irrigation pumps - pumping, heat recovery optional
Direct Combustion Options
Hot water boiler - space heat, process and cleanup hot water
Hot air furnace - space heat
Direct fire room heater - space heat
Adsorption chiller - cold water production, heat recovery optional

Figure 6.3 Biogas Use Options



System Operation Plan

A system operating plan must be developed to determine how to use the biogas. Tables 6.4 and 6.5 list important factors in developing a biogas use option. The most practical approach is to asses the energy use patterns and biogas production patterns and then select the biogas use that will fill the energy needs when using the majority of biogas production. Electricity is the energy form used on farms in the largest quantity on a continuous basis.

Table 6.4 Important Factors - Biogas Supply

1) Biogas is produced year round
2) Biogas storage is very expensive
3) Biogas production from heated complete mix and plug flow digesters should be stable, if manure collection is stable
4) Biogas production from covered lagoon digesters will vary seasonally
5) Digester may require heat

Table 6.5 Important Factors - Biogas Use

1) Space heat requirements vary seasonally
2) Space cooling requirements vary seasonally
3) Product refrigeration requirements are usually continuous, though total requirements vary seasonally
4) Electricity use may be widely variable on a daily and seasonal basis
5) Electricity use is variable between farms and management techniques
6) Adsorption chillers and engine driven uses can recovery hot water
7) Digester may require heat

Selecting and Sizing Biogas Use Options

Gas use must be matched to biogas availability and energy requirements. This section presents general considerations, biogas use options and components. Most gas use options are direct fuel substitution options whereas electricity production involves many possible scenarios. Sizing of equipment components is done in the model.

Selecting an Appropriate Gas Use Option

The most appropriate biogas utilization is replacement of purchased energy for heating, cooling or electricity. A gas use should be selected to maximize economic return. Consider Tables 6.3 and 6.4 and review the farm operation and the farm energy bills to determine candidate biogas uses.

Considerations

Value of Energy. The most important issue in biogas use is the value of the energy replaced by biogas.

Biogas Production Volume. Daily biogas volume is the limiting factor in selected biogas use options because practical biogas storage is limited.

Biogas Requirement of Gas Use Equipment. Table 6.6 summarizes the estimated BTU requirements of various biogas use options.

Location. Energy utilization equipment should be located in an area of the farm frequented by farm personnel. Short distances for the transmission of biogas and hot water through buried pipes are preferable. All buildings and equipment should be installed with adequate room for servicing and in accordance with all building codes. All spaces should be properly ventilated with adequate air inlet and exhaust. A gas detection monitor and alarm is recommended.

Heat Recovery for Digester. Plug flow and complete mix digesters require a portion of the biogas energy be returned as hot water to heat the digester.

Exhaust Stacks. Exhaust stacks should be non-corrodible material. Stacks should not discharge near ventilation intakes.

Table 6.6 Equipment Biogas-BTU Use Estimates (Estimation purposes only)

Assumes biogas is 600 - 750 BTU/ft^3

Engine Fuel Options
Biogas Fueled Engine at 23% efficiency
Engine-driven generator - 15,000 biogas BTU/kWh

Direct Combustion Options
Hot water boiler - Natural gas BTU requirement x 110%
Hot air furnace - Natural gas BTU requirement x 110%
Direct fire room heater - Natural gas BTU requirement x 110%
Adsorption cooling - 3 to 30 ton/hr standard - 27,500 biogas BTU/hr/ton cooling
- 30+ ton double effect - 13,500 biogas BTU/hr/ton cooling

Components

Gas use components are described by function. An operating plan must be developed prior to selecting components to allow proper sizing.

Biogas Fueled Internal Combustion (IC) Engines.

Natural gas or propane engines can be converted to burn treated biogas by modifying carburetion and ignition systems. Gas treatment is usually not necessary if proper maintenance procedures are followed.

Biogas can fuel engine-driven refrigeration compressor and irrigation pumps. This equipment is commercially available and can be used in place of existing units with proper modifications. However, irrigation pumping is generally intermittent, and refrigeration would represent a relatively small component of the biogas use potential of a dairy.

The most common and popular use of biogas is to fuel an engine-generator to produce electricity for on farm use or off farm sale. Hot water for digester heating and on farm uses can be recovered from the engine.

The price, quantity and pattern of electric and thermal energy consumption must be analyzed to assess potential project returns. An electricity value in 1996 of $0.06 per kiloWatt-hour (kWh) is probably a minimum value for electricity at which biogas-fired electricity generation can be feasible.

Available Capacities. Natural gas engines are available with capacities between 15 and 200 kW.

Thermal and Electrical Efficiencies. A biogas fueled engine-generator will normally convert 18 - 25% of the biogas BTUs to electricity.

Control Systems. Commercial control systems for engine-generators are well developed. It is noted that the control system must operate in the harsh environment of a farm and excess automation often fails where simple manual and mechanical controls usually succeed.

Air Emissions. Biogas engines less than 200 horsepower (150 kW) generally meet all California air pollution restrictions without modification if run with a lean fuel mixture.

Electricity Generation Options

Isolated vs. Parallel Power Production. A farm may choose to use a stand-alone engine-generator to provide all or part of its own electricity as an "isolated" system or operate connected to and mixing electricity with the utility "in parallel".

An isolated system must be able to function continuously, without interruption, to meet fluctuating levels of electricity demand while maintaining a smooth and steady 60 cycle current. Varying electric loads or large motor starting loads can lead to drift in the 60 cycle current. Drift results in wear on motors, speed up or slow down of clocks and timers, and operating problems with computers and programmable logic controllers.

Isolated systems require a sophisticated control system and a gas reservoir to meet changing loads. They are generally oversized to accommodate the highest electrical demand while operating less efficiently at average or partial load.

A parallel system is directly connected to the utility and matches the utility phasing, frequency and voltage so that farm produced power blends directly with utility line power. A utility intertie panel with safety relays is required to operate in parallel and to disconnect the farm generator if there is a problem with either the utility or the farm generation.

Parallel operation allows the farm generator to run at a constant output regardless of farm demand. Constant output allows more efficient use of biogas and less wear on the engine. The engine-generator can be sized for the biogas availability as opposed to maximum farm requirements. The farm buys power when required and sells power when overproducing. The utility is the system backup if engine maintenance is required.

Generator Options

Induction Generators vs. Synchronous Generators. A synchronous generator will operate either isolated or in parallel. The synchronous generator can provide electricity to the farm if the utility is shut down. Synchronous parallel generation requires a sophisticated intertie to match generator output to utility phase, frequency and voltage.

An induction generator will only operate in parallel with the utility and cannot stand alone. Induction generation derives its phase, frequency and voltage from the utility. Fewer and less sophisticated relays are required to protect the utility. Negotiations with a utility for intertie of a small induction generator are generally much easier.

Utility Intertie Requirements

Each utility has intertie requirements for protective relays to disconnect the generator automatically if the power line near the farm is accidentally broken or there is a problem with the generator. These relays are necessary for protection of farm and utility personnel. It is recommended that a professional familiar with intertie equipment negotiate with the utility and supply the appropriate gear. Negotiation is necessary because of the potential cost of the intertie. Solid state relays and electromechanical relays perform the same function, however electromechanical relays may cost 10 times more. A utility may need high cost relays for very large power producers but lower cost relays operate well for farm scale installations.

Operating Schemes

The key issue in developing a profitable biogas recovery system is the value of the energy to the owner. A careful review of utility rates and interconnection requirements are necessary prior to selecting the operating mode. Negotiation is appropriate for farm scale projects as most rules are set up for very large independent power producers.

Generation for On-farm Use. Electricity production is attractive because farms use electricity continuously. In addition, hot water for digester heating and farm use can be recovered from the engine. The minimum size engine-generator to economically produce electricity depends upon electricity usage and the value of electricity to the farm.

Sale of Electricity to the Utility. Under Section 210 of the Federal Public Utility Regulatory Policies Act of 1978 (PURPA) utilities must purchase power produced by qualifying cogenerators and small power producers. Biogas fueled electricity generation qualifies by definition. However, the utilities seldom offer reasonable purchase prices. Energy may be more profitably sold to a neighboring facility and this option should be investigated.

Preferred Operation Scheme. In 1997, the preferred operating scheme is a "surplus sale" where a farm produces electricity in parallel for use on farm with excesses sold and shortfalls purchased because of the low sale value of the excess electricity. An ideal agreement would be a monthly offset of excess kilowatts sold off farm against any power purchased on farm with appropriate payment or credit.

Effects of Utility Rate Structures. The farm has to be careful in rate analysis because high "demand" charges can negate half of the value of the electricity produced. "Demand" is usually the highest rate of electricity consumption for 15 minutes during a month. To offset demand charges, a generator must run 99.96% of the time to avoid demand charges during a 15 minute demand window each month. Some utilities offer a "backup" or "standby" charge which is usually a lower fee than a demand charge.

Utilities also offer a "buy - sell" agreement where the utility pays for all electricity produced and the farm pays for all electricity used. In 1996, most utilities buy electricity for approximately 25% of the sale price to the farm.

Operation and Maintenance Requirements - Biogas Fueled Engines

Engine. The engine manufacturer should supply an operation and maintenance schedule. A biogas engine should be inspected daily for adequate coolant and lubricant. Oil should be changed regularly to protect the engine. All engine mechanical safety devices should be checked monthly for proper function. Other engine components such as spark plugs will require maintenance on a monthly to yearly basis. Normal engine wear will require valve jobs every 6 to 24 months and engine rebuilding or replacement every 2 to 4 years.

Engine Controls. Engine controls require periodic repair or replacement.

Electric Generator. Generator bearings may require lubrication annually.

Utility Intertie Safety Devices. These devices should be checked annually for proper function.

Engine Driven Refrigeration Compressors and Irrigation Pumps. The manufacturer should supply an operation and maintenance manual. This application has not been demonstrated on-farm.

Direct Combustion Options

Hot Water Boiler

Farms require hot water on a year-round basis but usually far less than could be produced from biogas available from most farms. A modified commercial cast iron natural gas boiler can be used for most farm applications. The air fuel mix will require adjustment and burner jets will have to be enlarged for low BTU gas. All metal surfaces of the housing should be painted. Flame tube boilers may be used if the exhaust temperature is maintained above 300 degrees F to minimize condensation. High H_2S concentration in the gas may result in clogging of flame tubes.

Available Capacities. Cast iron boilers are available from 45,000 BTU/hr and larger.

Thermal Efficiencies. Conversion efficiencies are 75 - 85%.

Control Systems. Typical commercial control systems supplied with boilers are used to control boilers.

Operating Schemes. The boiler would be sized to produce all the heat required for the digester (if a heated digester is used) plus the maximum demand of the heat use system.

Air Pollution Potential. In most applications, a California approved low NO_x boiler can be used. In virtually all known farming areas, H_2S control would not be needed as the mass produced would be below control limits. Gas treatment would reduce potential SO_2 emissions.

Forced Air Furnaces

California farms generally do not have a year around need for heat. A hot air furnace can be fueled by surplus biogas or by biogas from a covered lagoon. It is difficult to recover heat for digester heating from a hot air furnace. Forced air furnaces are manufactured from thin metal and depend on metal to air heat exchange. Corrosion resistant models are not available, therefore gas treatment for water and hydrogen sulfide removal is needed.

Available Capacities. Forced air furnace are with capacities from 40,000 BTU/hr and up.

Thermal Efficiencies. Conversion efficiencies are 75 - 85%.

Control Systems. Typical commercial control systems supplied with furnaces are used to control forced air furnaces.

Operating Schemes. It would be unusual in California to find a hot air use on a farm that could consume all of the available biogas production potential.

Air Pollution Potential. In most applications, a California approved low NO_x furnace could be used. Gas treatment would reduce potential SO_2 emissions.

Direct Fire Room Heaters

Direct fire room heaters are commonly used in hog farrowing and nursery rooms. A farm will typically have multiple units. Some heat is required virtually every day of the year. Commercial models of this equipment can be operated using treated biogas. Burner orifices should be enlarged for low BTU gas.

A direct fire heater can be fueled by surplus biogas or by biogas from a covered lagoon. It is difficult to recover heat for digester heating from a direct fire room heater. Biogas would be burned directly in the room for heat, therefore, biogas treatment would be necessary to remove water and hydrogen sulfide.

Available Capacities. Direct fire room heaters are available in a wide range of sizes from 40,000 BTU/hr and larger.

Thermal Efficiencies. Conversion efficiencies are generally 85 - 90%, as all gas is burned in the room.

Control Systems. Typical commercial control systems supplied with the units are used to control direct fire heaters.

Operating Schemes. The operating scheme would depend upon the balance of biogas supply and maximum demand of installed heaters. Biogas could be supplied to as many heaters as the winter gas production could support. However, seasonal daily heat demand could be less than the production potential and therefore a portion of the collected gas would likely be wasted.

Air Pollution Potential. Most direct fire room heaters are smaller in capacity than covered by air pollution regulations. Gas treatment would eliminate potential SO_2 emissions.

Adsorption Chiller

Gas-fired adsorption chillers can be operated using treated biogas as a fuel. Chillers can be used to produce cold water for milk cooling or air conditioning. Double effect chillers, producing hot and cold water simultaneously, are available for applications over 30 tons and could be coupled with a heated digester. (one ton cooling = 12,000 BTU/hr)

Dairies cool milk every day of the year. Chilled water or glycol can be used in milk precoolers in place of well water. Units are under development that should produce glycol at temperatures less than 35° F.

Corrosion resistant models are not available, therefore gas treatment for water and hydrogen sulfide removal is needed.

Available Capacities. Adsorption chillers are available from 1 ton of cooling per hour and larger.

Thermal Efficiencies. 50% of the biogas BTUs will be delivered as cooling.

Control Systems. Commercial control systems supplied with the units control adsorption chillers.

Operating Schemes. Milk cooling requirements do not vary widely over the year. Average cow manure production can be digested to produce about 40,000 BTU/day. However, milk cooling would only require about 5,000 BTU per cow per day (12% of the potential).

Air Pollution Potential. Most chillers are smaller in capacity than the minimum output covered by air pollution regulations. Larger applications would use California approved low NO_x units. Gas treatment would eliminate potential SO_2 emissions.

Operation and Maintenance - Direct Combustion Options

Hot water boilers, hot air furnaces, direct fire room heaters, and adsorption chillers should be inspected weekly for leakage, accumulation of deposits on burners and lubricated as required.

Capital Cost Factors

For cost estimation purposes in the model it is assumed that an engine-generator price includes switch gear. Transformer changes were not itemized or estimated because virtually all farms have transformers large enough to handle the generator output.

Component Costs. For the cost analysis model, a range of gas flows were selected and the appropriate size gas use component was identified. Equipment suppliers were contacted and December 1995 pricing was developed for the equipment. Table 6.7 shows the gas use component pricing based on Table 6.5 assumptions.

Operation and Maintenance Costs

Direct Combustion Gas Uses. It was assumed based upon limited experience and consultation with others that operation and maintenance costs, would be equal to 5% of capital cost on an annual basis.

Engine Generator. The industry accepted standard for engine operation and maintenance is $0.015/kWh with professional maintenance staff. As farms do most of the routine engine maintenance themselves and only contract for major work, experience has shown the cost of maintenance to be $0.01/kWh.

Model Inputs

There are no required model inputs. Electricity generation is the default choice for gas use in California. The operator may manually price another option using Table 6.7.

Table 6.7 Uninstalled Equipment Sizing and Approximate Costs

NOTE: THESE COSTS FOR ESTIMATION ONLY

Gas Output - 600 BTU Gas

Ft3/d	3000	6000	9000	15000	21000	27000	33000
SCFM	2	4	6	10	15	19	23
Boiler	$ 2,060	$ 2,495	$ 2,898	$ 4,600	$ 5,100	$ 5,600	$ 6,100
Hot Air Furnace	$ 620	$ 860	$ 3,938	$ 6,563	$ 9,188	$11,813	$14,438
Room Heater	Custom installation only						
Adsorption Chiller - Tons	3	6	8	15	20	25	30
Unit Cost	$ 3,000	$ 6,000	$ 8,000	$11,250	$10,000	$12,500	$15,000
Double Effect Chiller - Tons	NA	NA	NA	30	40	50	60
Unit Cost	NA	NA	NA	$38,100	$50,800	$63,500	$76,200
Engine-Generator kW	5	10	15	25	35	45	55
Unit Cost	NA	NA	$10,500	$17,500	$24,500	$31,500	$38,500
Heat Recovery	NA	NA	$ 4,500	$ 7,500	$10,500	$13,500	$16,500

Ft3/d	39000	45000	52500	60000	75000	90000
SCFM	27	31	36	42	52	63
Boiler	$ 6,600	$ 7,100	$ 7,400	$ 7,600	$ 8,000	$ 9,600
Hot Air Furnace	$17,063	$19,688	$22,969	$26,250	$32,813	$39,375
Room Heater	Custom installation only					
Adsorption Chiller - Tons	35	40	50	60	75	90
Unit Cost	$17,500	$ 10,000	$ 12,500	$ 15,000	$ 18,750	$ 22,500
Double Effect Chiller - Tons	70	80	100	120	150	180
Unit Cost	$88,900	$101,600	$127,000	$152,400	$190,500	$228,600
Engine-Generator kW	65	75	87.5	100	125	150
Unit Cost	$45,500	$ 52,500	$ 61,250	$ 70,000	$ 87,500	$105,000
Heat Recovery	$19,500	$ 22,500	$ 26,250	$ 30,000	$ 37,500	$ 45,000

References

1. The Handbook of Biogas Utilization, Environmental Treatment Systems, Inc., Southeastern Regional Biomass Energy Program, Tennessee Valley Authority, Muscle Shoals, Alabama 35660, July 1996
2. Robar Corporation, Evansville, IN
3. Yazaki Corporation, Dallas, TX

VII. Economic Optimization of Biogas Systems for use on California Dairies and Hog Farms

The economics of anaerobic digestion control the ultimate acceptance of the technology. The reason for a majority of farms to consider a digester is to produce products that increase farm profitability. Digesters have been installed to control odors that threatened the continuation of farm operations. However, these installations were more often forced on the farm rather than willingly selected. Other countries use anaerobic digestion technology to reduce the pollution potential of animal wastes and regulations encourage adoption of this technology.

This chapter examines factors that affect the profitability of anaerobic digestion systems in California. Covered dairy lagoons and plug flow dairy digesters are the most potentially usable systems. Covered lagoons for pigs are economically feasible, however, California has a very small pig population.

CMEM Model Description and Operations

The CMEM model was used as the basis for identifying key factors affect the profitability of anaerobic digestion systems in California. Figure 7.1 shows the flow path the model uses to arrive at a Net Present Value (NPV) for a farm being analyzed. The model uses input values for animal numbers, farm location, farm characteristics and waste management techniques to select an appropriate digester type. A digester volume is selected based on the inputs. The digester is then sized and a costing function selects the costs for the various components of the digester. Biogas production potential is used to select the gas transmission, gas handling and engine generator costs. Biogas potential is also used to calculate potential revenues. Costs and revenues are taken into a spread sheet where the NPV of the project is calculated. *The model is for prefeasibility estimation purposes only.* Individual farms have specific characteristics and equipment that should be addressed in a formal feasibility and design study.

Model Values versus Energy Use on California Dairy and Hog Farms

It is beyond the scope of this report to provide modeling for energy use on farms. Farms in California generally use energy in similar patterns by region, but equipment installed at these farms varies, often significantly. Appendix J summarizes energy use data collected by James Young of the CEC at 10 different dairies. The appendix includes information about the dairy equipment installed; the operating time of the installed equipment; the number of meters where a dairy is buying electricity; the total electrical usage; the cost per unit of electricity; and the kW/cow/day consumed. The study shows that dairy farms use between 1 and 2.5 kW/cow/day for the milking dairy itself, not including irrigation pumping.

Hog farms are not present in sufficient numbers to have common equipment and equipment operating patterns. Therefore, the CMEM model assumes the farm can use all the energy produced.

Factors to be Evaluated

"TopRank", a commercially available program, (Palasade Corporation, 31 Decker Road, Newfield, NY 14867) was used to identify significant factors affecting the net present value analysis (NPV) in the CECCOW and CECPIG models. Once significant factors were identified, a "base case" was developed with significant variables identified. Multiple what-if simulations were run holding all base case variables unchanged except one, which was varied. The same process was followed for all variables, until a ranking of factors was achieved and tables developed. The results of the multiple runs are presented as graphs in Appendix H.

Base Case

The base case values are those values assumed to be typical for farms in California. The base case values have been varied to find the factors most significantly affecting the NPV. Table 7.1 shows base case values.

Base Case Analysis

The model was run manually by substituting expected minimum and maximum ranges (80% and 120% respectively) of base case values to determine the sensitivity of NPV of the project. Animal population was shown to be the value most affecting NPV. Therefore a base case for 3 animal populations were run and compiled. Figure 7.1 shows the dramatic difference in NPV at different cow populations for dairy waste management types.

Covered Lagoon - Alternatives Affecting Net Present Value

The most common farm in California that would use anaerobic digestion would be a flush freestall or flush feedlane dairy. All factors discussed also apply to covered pig waste lagoons. Figures 7.2 shows major variations on the base case of interest to farmers. Sensitivity of the net present value to individual factors is discussed later in the section. Major factors are highlighted here.

Farm Size. The number of animals is very significant due to economies of scale in construction.

Materials Selected for Floating Cover. Use of expensive cover materials ($2/ft^2 installed) usually results in a negative NPV. Almost all systems using the model Option 1 (expensive) cover material show a negative NPV. Therefore, cover material cost is very significant in the net present value analysis.

All Cash Investment. If the system is purchased for cash rather than financed, the net present value of the purchase is sometimes used as a "true" value of the project. The cash investment NPV is less than the financed NPV.

Effect of Not Digging a New Lagoon. If an existing lagoon can be covered, profits are far greater than building a new lagoon. Therefore, covering an existing properly sized lagoon should almost always be a profitable investment.

Figure 7.1 Operations in CMEM Model

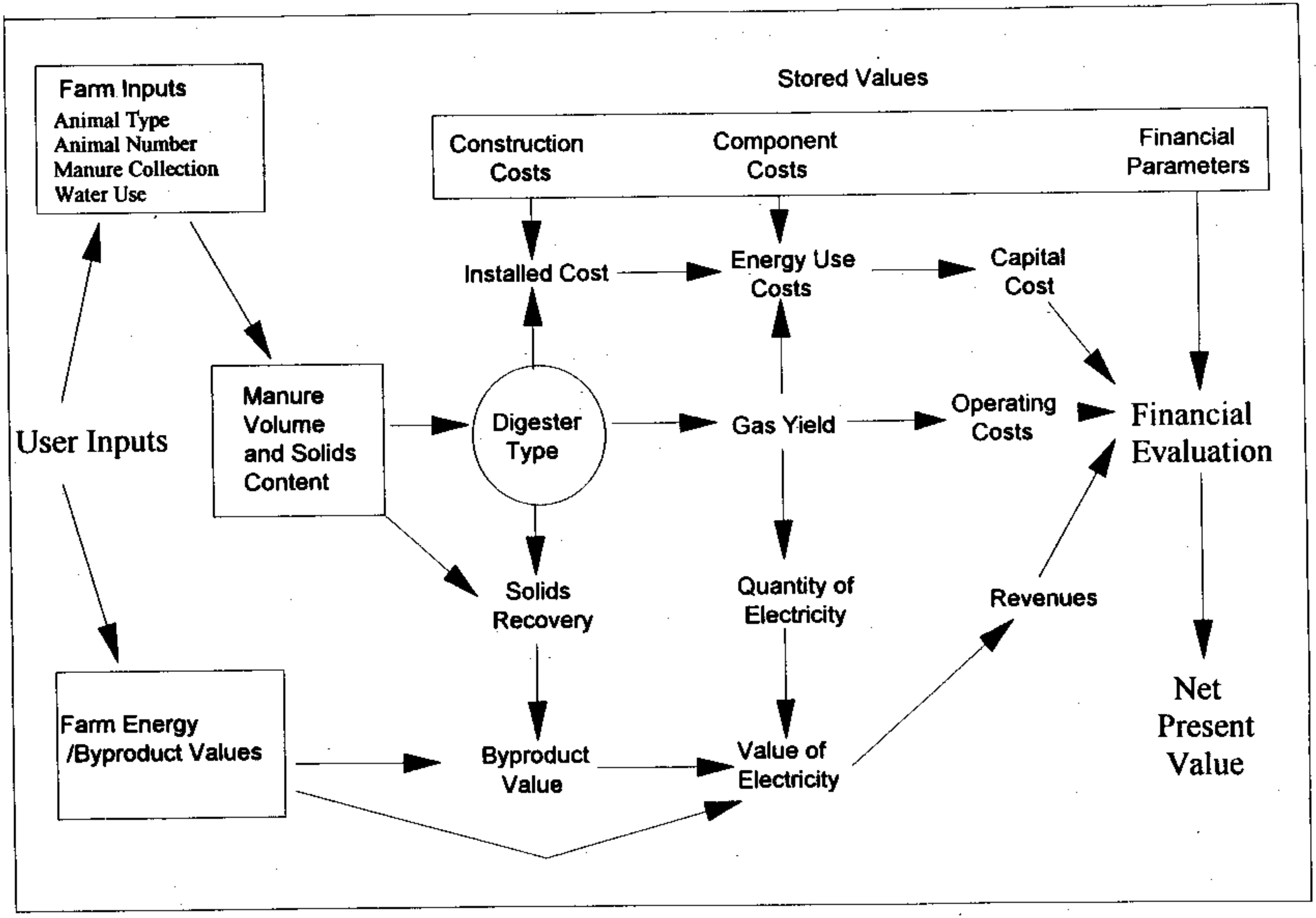
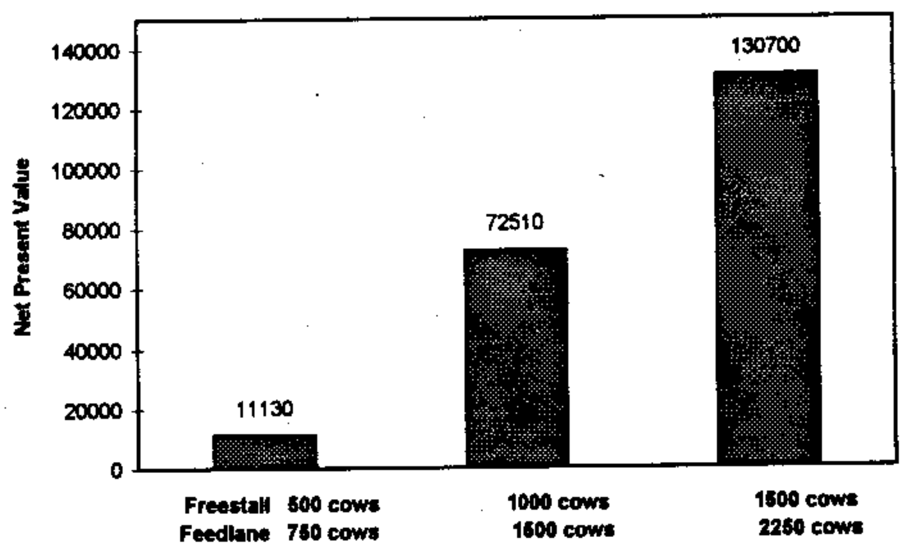


Table 7.1 Base Case Assumptions

Financial		**Revenue**	
Project Life	15 years	Electricity for use	$0.075/kWh
Loan Period	10 years	Electricity for sale	$0.03/kWh
Down Payment	20 %	Digested cow solids	$4.00/yd
Loan Interest Rate	8 %	Undigested cow solids	$ 0 /yd
Discount Rate	14 %	Pig solids	$ 0 /yd
Tax Rate	35 %	Hot water for cows	$ 6/cow/yr
Depreciation	straight line	Heat for pigs	15% of BTUs
O&M Costs	$ 0.015 /kWh		
Energy Cost Growth	3 %		
Operations		**Construction**	
Engine Efficiency	14,000 BTU/kWh	Labor	$160 /manday
Engine Operation	85 % of all hours	Lagoon sideslope	1.5:1
Fresh water use	100 gal/milking cow/d	Lagoon depth	20 ft
Dairy Flush water	14 gal/gal manure	Inexpensive Cover	$0.60/ft2

Figure 7.1 Base Case - Net Present Value Covered Lagoon for Flush Dairy



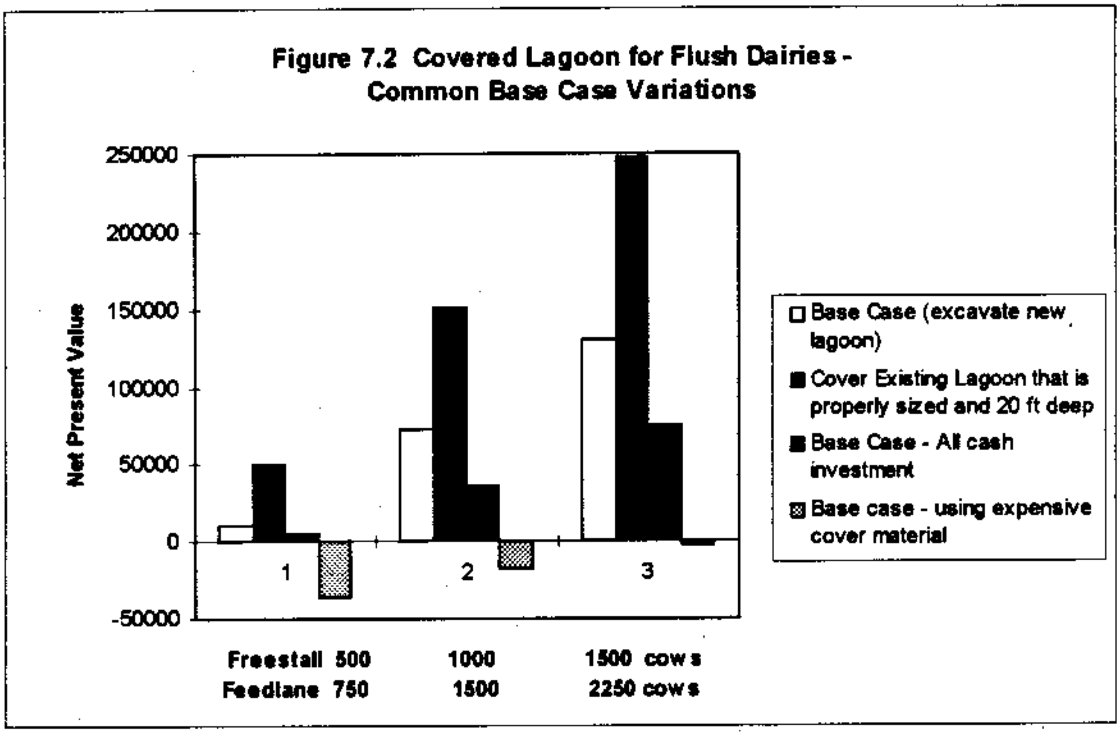


Figure 7.2 Covered Lagoon for Flush Dairies - Common Base Case Variations
Net Present Value
250000
200000
150000
100000
50000
0
-50000
1
2
3
Freestall 500
Feedlane 750
1000
1500
1500 cows
2250 cows
Base Case (excavate new lagoon)
Cover Existing Lagoon that is properly sized and 20 ft deep
Base Case - All cash investment
Base case - using expensive cover material

Sensitivity of Net Present Value to Variation of Factors

The most significant factors affecting NPV for flush collected manure are listed in order of sensitivity of NPV to changes in their value in Table 7.2 for dairies and Table 7.3 for pigs. The most significant factors for scrape collected dairy manure plug flow digesters is shown in Figure 7.4. Other factors, such as labor costs were tested but found to have a very limited impact and therefore not included. Graphs showing the effect of variation of individual factors on NPV are contained in Appendix H.

Table 7.2 Ranking of Sensitivity of Cost Components for Dairy Type and Lagoon Type

	Feedlane Flush, Cover Old Lagoon		**Feedlane Flush, New Lagoon**
Rank	Cost Component	Rank	Cost Component
#1	Cow Number	#1	Cow Number
#2	Electricity $/kWh	#2	Electricity $/kWh
#3	Generation efficiency BTU/kWh	#3	Generation efficiency BTU/kWh
#4	Operating up time	#4	Operating up time
#5	Discount Rate	#5	Capital Cost
#6	Capital Cost	#6	Discount Rate
#7	Depth - ft	#7	Loan Interest Rate
#8	Loan Interest Rate	#8	Depth - ft
#9	O&M	#9	Flush Volume
#10	Energy Cost Growth	#10	O&M
#11	Hot Water Value	#11	Fresh Water Use
#12	Flush Volume	#12	Energy Cost Growth
#13	Fresh Water Use	#13	Hot Water Value

	Freestall Flush, Old Lagoon		**Freestall Flush, New Lagoon**
Rank	Cost Component	Rank	Cost Component
#1	Cow Number	#1	Cow Number
#2	Electricity $/kWh	#2	Electricity $/kWh
#3	Capital Cost	#3	Capital Cost
#4	Discount Rate	#4	Discount Rate
#5	Depth - ft	#5	Loan Interest Rate
#6	Loan Interest Rate	#6	Depth - ft
#7	Operating up time	#7	Flush Volume
#8	O&M	#8	Operating up time
#9	Generation efficiency BTU/kWh	#9	O&M
#10	Flush Volume	#10	Generation efficiency BTU/kWh
#11	Energy Cost Growth	#11	Energy Cost Growth
#12	Utility buyback	#12	Fresh Water Use
#13	Hot Water Value	#13	Utility buyback
#14	Fresh Water Use	#14	Hot Water Value

Table 7.3 Ranking of Sensitivity of Cost Components for Pig Farm Covered Lagoon

Farrow to Nursery - Old Lagoon

Rank	Cost Component
#1	Sow Number
#2	Electricity Value
#3	Generation efficiency - BTU/kWh
#4	Engine Uptime
#5	Flush Volume
#6	Discount Rate
#7	Capital Cost
#8	Loan Interest Rate
#9	Heat Value
#10	Operation and Maintenance
#11	Lagoon Depth

Farrow to Finish - Old Lagoon

Rank	Cost Component
#1	Sow Number
#2	Electricity Value
#3	Generation efficiency - BTU/kWh
#4	Engine Uptime
#5	Discount Rate
#6	Flush Volume
#7	Capital Cost
#8	Heat Value
#9	Loan Interest Rate
#10	Operation and Maintenance
#11	Lagoon Depth

Farrow to Nursery - New Lagoon

Rank	Cost Component
#1	Sow Number
#2	Electricity Value
#3	Generation efficiency - BTU/kWh
#4	Flush Volume
#5	Engine Uptime
#6	Capital Cost
#7	Discount Rate
#8	Loan Interest Rate
#9	Heat Value
#10	Operation and Maintenance
#11	Lagoon Depth

Farrow to Finish - New Lagoon

Rank	Cost Component
#1	Sow Number
#2	Electricity Value
#3	Generation efficiency - BTU/kWh
#4	Flush Volume
#5	Engine Uptime
#6	Discount Rate
#7	Capital Cost
#8	Loan Interest Rate
#9	Heat Value
#10	Operation and Maintenance
#11	Lagoon Depth

Table 7.4 Most Significant Inputs in the Plug Flow Model

Rank	Component
#1	Electricity $/kWh ***(#2 @ 500 cows)
#2	Capital Cost ***(#1 @ 500 cows)
#3	Engine Uptime
#4	Engine Efficiency BTU/kWh
#5	Discount Rate
#6	Loan Interest Rate
#7	Value of digested solids
#8	O&M
#9	Energy Cost Growth
#10	Hot Water

Construction Factors

Cover Cost - The lagoon cover is the key cost component. At $0.60/ft^2 (less expensive material) all base cases, except the 500 sow farrow to feeder with a new lagoon, had positive a NPV whereas at $2/ft^2 (expensive material) only the 1500 cow new and old lagoon base case still had a positive NPV. Therefore, selection of cover material and control of costs is very important.

Lagoon Depth - Lagoon depth determines lagoon surface area for the selected design volume. Greater depth means smaller surface area and a smaller lagoon cover. The lagoon cover is the most costly portion of the capital cost. Greater depth generally showed higher NPV.

Revenue Factors

Electricity Value - Electricity value on farm is the key revenue component. If the electricity can offset farm purchases at the retail value, most California farms can have a profitable investment. A problem with this assumption in 1997 is that rate structures in most utilities will change in response to deregulation. It is beyond the scope of this paper to analyze the hundreds of utility rates that could affect NPV. <u>Rate structure is as important as electricity value in determining the NPV.</u>

Buyback Rate - Buyback rate variation had a minimal effect on NPV. However, comparison of systems producing excess electricity for sale versus systems not selling electricity off the farm found that systems selling excess electricity had lower NPV suggesting that selling electricity at low rates was not a good use of money. <u>Therefore, sizing systems based on-farm electricity use rather than maximum potential output should have a better NPV.</u>

Value of Undigested Solids - Flush dairies that assign a small value to recovered solids show a higher NPV than if no value is assigned. Historically, a farm with a digester does a better job of realizing value of waste byproducts.

Value of Digested Solids - Digested solids from plug flow digesters have demonstrated a much higher value than undigested solids. Sale of these solids is relatively important for success of a plug flow system and its NPV. Variation of solids value found a minimum value of $3.50/yd^3 necessary for a 500 cow digester to succeed.

Heat Value - Hot water or hot air to offset on farm propane use is a small part of the revenue stream. Variation of the value of this heat had a minor effect on NPV. However, loss of this revenue would reduce NPV.

Inflation of Energy Cost - At today's low rate of energy value inflation, minimal effect on NPV was found.

Farm Operation Factors

Flush Volume and Fresh Water Use Higher volumes of water use require larger volume lagoons which increases capital cost with no increase in return.

Financial Factors

Interest Rate - As interest rate increases it cancels revenues and at some rate will drive the NPV of the project to zero.

Discount Rate - Discount rate is a measure of the value of money in comparison to alternative investments. Increasing discount rate sufficiently will reduce the NPV of a project to zero, suggesting that the investment would not be worth the risk associated with the investment.

Digester System Operation Factors

Engine Efficiency and Engine Uptime - These are key components of electricity value to a project. Equipment selection and operator skill can optimize these components.

Operation and Maintenance - A 20% variation around the base case produced little change in NPV. Therefore, normal maintenance is not a major factor

Farm Type Factors

Covered Lagoons

Two types of dairies and most hog farms are candidates for covered lagoons. There are hundreds of freestall flush dairies and feedlane flush dairies in California. This study looked at the NPV of both types of farms, covering either an existing lagoon or a new lagoon.

Feedlane Flush Dairies. The analysis showed that, after farm size, the most important factor affecting NPV is the value of electricity to the farm. For feedlane flush, engine efficiency and operating time are very significant. The top three sensitivity factors all affect revenue. Capital cost is the next most important factor for a new lagoon, while capital cost drops below financial factors for old lagoons. Financial factors - interest and discount rate, are significant because of their effect on cash flow and measures of performance. Farm construction and operation factors, lagoon depth, and water use are the third significant group of sensitive factors. Some California dairies use significant amounts of water that would dictate increased lagoon size and higher costs and would negatively impact NPV. Surprisingly, the value of hot water and electricity inflation affect the NPV less than other factors.

Freestall Flush Dairies. The analysis showed that, after farm size, the most important factor affecting NPV is the value of electricity to the farm. The next three factors affecting sensitivity are all cost related. Freestall flush dairies can produce more electricity than needed on farm and sell excess electricity at very rates. Therefore, capital cost is the next most important factor because of the diminished returns from selling excess electricity. Financial factors, interest and discount rate are significant because of their effect on cash flow and measures of performance. Depth is as important in lagoons as financial factors because of its effect on cover cost. Revenue factors and farm operation factors - engine efficiency, operating time, operation and maintenance and flush volumes are the next significant group of factors. Some California dairies use significant amounts of water that would dictate increased lagoon size and higher costs and would negatively impact NPV. Again, fresh water use, the value of hot water and electricity inflation affect the NPV less than other factors.

Flush Pig Farms. Pig production is limited in California. Two types of farms, farrow to feeder and farrow to finish, were analyzed using the base case assumptions with adjustments for flush and freshwater volume appropriate for pig farms. Covering an existing or a new lagoon were compared. Finishing farms were not modeled because it is known that a finishing farm has a very low need for energy, but a very high potential for energy production. Therefore, most energy from a finishing farm must be sold off the farm at rates very near the cost of production. This is known to be an unprofitable venture.

NPV is most sensitive to pig population. Electricity value changes were the second most important factor affecting NPV. Engine uptime and engine efficiency, as components of electrical revenue are also key factors because of the close match between potential electrical production and potential use. In pig farms, flush volume is very important because of its effect on lagoon size. Cost factors - capital cost, interest rate and discount rate were less significant than revenue factors in the sensitivity of NPV. Heat value, operation and maintenance, and lagoon depth had the least effect on NPV of all identified factors.

Similar groupings of factors are found for all pig farms. This result can be explained by fact that in almost all known cases, a sow farm can utilize almost all of the energy it can produce. Valuing the energy at retail rates should give a positive NPV. Most factors in a pig farm are directly proportional to pig population, limiting the possible changing in ranking of factors.

Scrape Dairies

Scrape Collected Dairy with Plug Flow Digester. The analysis showed that after cow population, the most important factor affecting NPV is the value of electricity to the farm. Most scrape dairies can produce more electricity than needed on farm and sell excess electricity at very low avoided costs. Therefore, capital cost is the second most important factor because of the diminished returns from selling excess electricity. Revenue factors, engine efficiency, and operating time are the next significant group of factors. Financial factors, interest and discount rate are significant because of their effect on cash flow and measures of performance. Digested solids revenue is less significant than factors discussed above. Variation of operation and maintenance costs, energy inflation rate and the value of hot water have the least effect on NPV.

Optimization of Factors for Digesters

The model was run with each base case variable tested within a plus or minus 20% range while other base case factors were held at the original values. The 20% limits were selected as a reasonable range based on experience. Table 7.5 shows the value at which the NPV is zero within the range tested for covered lagoons. For example, for a 500 cow feedlane flush dairy, the NPV of the project goes to zero when the value of the electricity produced is reduced to \$0.064/kWh. The results are shown graphically in Appendix H. Table 7.6 shows the value at which the NPV is zero, when other variables are at the base case values for plug flow digesters. Therefore, to optimize the economics of a biogas system, these minimum or maximum values must be achieved for a digester project to have a positive NPV.

Table 7.5 Value of a Factor that Reduced NPV to Zero for a Covered Lagoon when the Factor was Varied by 20% Around its Original Base Case Value (All other factors held at Base Case Level)

		Old Lagoon			New Lagoon		
	Value	500 cows	1000 cows	1500 cows	500 cows	1000 cows	1500 cows
Feedlane Flush Dairy							
Electricity $/kWh	min	$ 0.064	$ 0.040	$ 0.040	$ 0.072	$ 0.062	$ 0.060
Capital Cost	max	dnz	dnz	dnz	107%	dnz	dnz
Engine BTU/kWh	max	dnz	dnz	dnz	15,000	16800	dnz
Engine Op %	min	72%	dnz	dnz	80%	dnz	dnz
Discount %	max	dnz	dnz	dnz	15%	dnz	dnz
Interest %	max	10%	dnz	dnz	8.50%	dnz	dnz
Lagoon Depth - feet	min	dnz	dnz	dnz	18	dnz	dnz
O&M $/kWh	max	dnz	dnz	dnz	$ 0.017	dnz	dnz
Flush - gal/gal manure	max	dnz	dnz	dnz	16	dnz	dnz
Fresh wtr Gal/cow/d	max	dnz	dnz	dnz	120	dnz	dnz
Energy Inflation %	min	dnz	dnz	dnz	2.40%	dnz	dnz
Hot Water $/cow/yr	min	dnz	dnz	dnz	$ 4.80	dnz	dnz
Freestall Flush Dairy		500 cows	1000 cows	1500 cows	500 cows	1000 cows	1500 cows
Electricity $/kWh	min	$ 0.07	$ 0.06	$ 0.06	$ 0.08	$ 0.07	$ 0.06
Capital Cost	max	110%	dnz	dnz	93%	120%	dnz
Engine BTU/kWh	min	dnz	dnz	dnz	11,200	dnz	dnz
Engine Op %	min	dnz	dnz	dnz	96%	dnz	dnz
Discount %	max	17%	dnz	dnz	11%	dnz	dnz
Interest %	max	10%	dnz	dnz	64%	dnz	dnz
Lagoon Depth - feet	min	15	dnz	dnz	30	12	dnz
O&M $/kWh	max	$ 0.02	dnz	dnz	$ 0.01	dnz	dnz
Flush gal/ gal/manure	max	dnz	dnz	dnz	11	18	dnz
Fresh wtr gal/cow/d	max	dnz	dnz	dnz	60	dnz	dnz
Energy Inflation %	min	dnz	dnz	dnz	40%	dnz	dnz
Buyback Rate $/kWh	min	dnz	dnz	dnz	$ 0.05	dnz	dnz
Farrow to feeder pig		500 sows		650 sows		>650 sows	
Electricity $/kWh	min	negative all cases		$ 0.06		$ 0.055	
Farrow to Finish		Positive NPV all test cases					

dnz - Did not go to zero in the plus or minus 20% range around the base case assumed value

Table 7.6 Value of a Factor that Reduced NPV to Zero for a Plug Flow Digester when the Factor was Varied by 20% Around its Original Base Case Value (All other factors held at Base Case Level)

		Value	500 cows	1000 cows	1500 cows
Scrape Dairy					
Electricity	$/kWh	min	$ 0.074	$ 0.050	$ 0.042
Capital Cost	% of base	max	1.05%	dnz	dnz
Engine	BTU/kWh	max	dnz	dnz	dnz
Engine Op	%	min	72%	dnz	dnz
Discount	%	max	16%	dnz	dnz
Interest	%	max	9%	dnz	dnz
Lagoon Depth - feet		min	dnz	dnz	dnz
O&M	$/kWh	max	$0.02	dnz	dnz
Energy Inflation	%	min	2%	dnz	dnz
Hot Water	$/cow/yr	min	$4.00	dnz	dnz
Solids	$/yd3	min	$3.50	dnz	dnz

dnz - Did not go to zero in the plus or minus 20% range around the base case assumed value

General Conclusions

Using reasonable base case assumptions, many anaerobic digester systems could be built in California that would have a positive NPV. The size of the farm is the most important factor, because larger facilities take advantage of significant economies of scale. The value of products must be adequate to support the level of investment necessary to build a digester system. Based on current energy prices this appears to be the case. However, the future value of electricity is very important and the most difficult to accurately analyze in general models, given the flux in utility deregulation. The capital cost factors, if they can be reduced, could significantly affect the NPV of potential projects. Each project must be analyzed in detail for the specific site conditions to determine its viability.

VIII. Model Testing against Sharp Ranch Covered Lagoon

Introduction

This Chapter compares the results predicted by CECPIG3.XLS versus the actual operations of Sharp Ranch's pig waste covered lagoon. Data used in the comparison were collected and reported to the California Energy Commission by Resource Conservation Management, Inc. (RCM) in 1994 and Roy Sharp in 1995. RCM catalogued biogas production and use on the farm. Sharp monitored and collected data on the lagoon biological performance, temperatures and gas quality. Sharp Ranch data are included as Appendix I. The studies were conducted a year apart and covered two different operating years, however farm operations did not vary significantly, except early in Sharp's study the covered lagoon was emptied of sludge, so two months of data were not usable.

Farm Description and Model Inputs

Sharp Ranch is a 500 sow farrow to finish facility. Most of the sows and boars are kept outdoors and their manure does not enter the lagoon. Manure is collected by a combination of flushing, washing, and pull plug pits. Manure flows to a collection pit and is pumped into the covered lagoon. Biogas is piped to the engine room about 400 feet away to a Waukesha 817, 75 kW engine-generator. Electricity is produced to offset farm requirements and hot air is ducted from the engine into the buildings for heat.

Table 8.1 is the population input for the model. Sharp Ranch energy information shown in Table 8.2 was input in the model. Manure management information in Table 8.3 was input into the model. Inputs were made in the Decisions sheet.

Table 8.1 Sharp Ranch Pig Population on Waste Management System

	Number	Type	Average weight- lb	Total weight- lb		Average weight- kg	Total weight- kg	
	Input here		***					
	40	sows	400	16,000		181.44	7,258	
	0	gilts	180	0		81.65	0	
	0	boars	500	0		226.80	0	
	484	piglet	8	3,872		3.63	1,756	
	750	prenursery	22	16,500		9.98	7,484	
	750	nursery	51	38,250		23.13	17,350	
	1,400	grower	95	133,000		43.09	60,329	
	1,400	finisher	185	259,000		83.92	117,482	
TOTALS	4,824	pigs		466,622	lb		211,660	kg

Table 8.2 Energy Input Information

Energy Use / Cost			
Stationary Uses	*Please select default with "y" or input actual information*		
DEFAULT		1 kWh/sow/d	
	y or n	Cost per Unit	Annual Cost
Use Default?	n		
Electricity	y	$ 0.116 $/kWh	$31,500 $/yr
Electricity Demand	n	$ - $/kW demand	60 Max kW demand
Utility buyback		$ 0.03 $/kWh	
Hot Water			
Propane	y	$ 0.70 $/gal	$ 4,360 $/yr

Table 8.3 Waste Management Information Input

Manure Collection	***note- input required to allow calculation*** *Please put a y for yes next to the type of manure collection group below.*			
	y or n	How many?		
Flush	y	4 flush valves	1,200 gal/flush	1 flushes /d
Hose wash	y	2 hoses	5 gal/min	20 min/day
Scrape	not used			

Water Usage	*Please put a y for yes next to the type of water use*	
		y or n
Nipple/bowl/trough waterers		y
Cold water pressure washer		y
Hot water pressure washer		n

Manure Treatment *Please put a y for yes next to the type of manure effluent treatment.*		Water surface			
	y or n	length - ft	width - ft	depth - ft	vol. - ft3
First Lagoon - waterline dimensions @ full	y	150	75	15	121,500
During spreading, how much is the single cell volume reduced?				0%	121,500

Model Runs and Results

The data above were put into the model and run. The first conclusion of the model was that the Sharp lagoon was too small and a new lagoon was needed. This is due to the volatile solids loading limitations of the model. Table 8.4 shows the new covered lagoon recommended by the model compared to the actual system at the Sharp Ranch.

Gas Production

Gas production estimates by the model were lower than measured at the Ranch. The model has historically underpredicted winter gas production and hence could be expected to have a lower average production. Review of gas quality monitoring data suggests occasional suction of air into the gas line or problems with gas sampling. Pulling air into the gas line could contribute to the average gas production measured.

Electricity Production

Table 8.4 shows that the model estimated electricity output to be higher with less gas than experienced on the farm. The comparison demonstrates loss of efficiency of a 75 kW generator run at 50% load versus a 40 kW generator run at 90% load.

Table 8.4 Model Output Versus Actual System at Sharp Ranch

	Model - New Lagoon		Actual	
Total Pig Number	4,824	pigs	4,824	pigs
Lagoon Influent Volume	3,175	ft3/d	3,175	ft3/d
Lagoon Volume under cover	251,532	ft3	121,500	ft3
Lagoon Length used	134	ft3	150	ft3
Lagoon Width used	134	ft3	75	ft3
Lagoon Depth	20	ft	15	ft
Lagoon Cover Dimension	13,352	ft2	11,250	ft2
Average Gas Flow	18,300	ft3/d	24,492	ft3/d
Engine-generator size	40	kW	70	kW
Average generator output	36	kWh/hr	31.4	kWh/hr

Benefits

The model output of benefits in Table 8.5 is actually quite close to those reported by RCM.

Table 8.5 Model Benefits Outputs Versus Actual System at Sharp Ranch

POTENTIAL BENEFITS	Model	Actual
Replacement of farm electrical purchases	$30,726	$31,300
Sale of excess electricity	$0	$254
Hot air from engine	$3,706	$4,360
Capacity Savings Potential	$0	$0
TOTAL POTENTIAL	$34,432	
TOTAL ACTUAL BENEFIT		$35,914

Analysis

The results were generally good from the model, however the cost of a recommended system would be higher in the model than the system actually used by Sharp. Therefore, data collected by Sharp were compared with model predictions. Differences are discussed below.

Loading Rate

The loading rate for the existing lagoon, 16 lb/1000 ft^3, is higher than the conservative value recommended by NRCS, 10 lb/1000 ft^3 and used in the model. Higher loading rates have been demonstrated to function successfully, however sludge builds up faster and the lagoon requires more frequent cleaning. The lagoon has been cleaned out once in 11 years. A lagoon in Arkansas loaded at 24 lb VS/1000 ft3 was producing and recovering methane, but needed cleaning after 6 years.

Lagoon Temperature

Data on lagoon temperature in Sharp's report were warmer than temperatures forecast by the model. Sharp Ranch lagoon is as much as 10 degrees warmer than forecast during the winter. However, the summer temperatures were as forecast. This is a problem when using regional climate models. The model uses regional data averaged for several counties, including some of the colder hills and mountain areas. Tulare is in the southernmost, driest, and warmest section of the climate zone.

Volatile Solids

Sharp reported monthly volatile solids content for his lagoon. Concentrations in the model-proposed new lagoon were 1/3 - 1/4 of the concentration measured by Sharp.

Remodeling

Therefore the model was rerun, forcing higher loading rates and using measured lagoon temperatures reported by Sharp and reasonable substitutions where data was lacking. Table 8.6 show the results of the remodeling. The model is reasonably close to the field measurements when the existing lagoon is modeled with loading rate between 14 and 16 lb/1000 ft3, which is the calculated loading rate at Sharp Ranch. The predicted average kWh output is also shown.

Discussion

The model predicted the benefits realized at Sharp Ranch quite accurately, however due to the conservative loading rate limit the lagoon and cover would have cost about 25% more. In the long run the larger lagoon would need cleaning less often. When actual measured temperature and loading rates were used, the model was reasonably close to predicting volatile solids concentration in the lagoon and average electrical output.

Table 8.6 Predicted Volatile Solids Concentrations at Different Loading Rates

	Actual	Model Loading Rate - lb/1000 ft3			
		9	14	16	18
	VS - mg/l	VS - mg/l	VS - mg/l	VS - mg/l	VS - mg/l
Jan 1995	1728	660	1700	2228	3100
Feb	1350	564	1460	1950	2800
Mar	1450	578	1476	1955	2800
Apr	1164	530	1361	1806	2500
May	1484	489	1249	1653	2400
Jun	1655	421	1079	1431	2000
Jul	1923	400	1074	1339	1900
Aug	1506	490	1034	1363	1900
Sep 1994	1232	408	1033	1365	1900
Oct	1200	484	1233	1627	2100
Nov	890 *	569	1445	1913	2700
Dec	1200 *	663	1675	2210	3100
Avg kWh	31	36	32	31	27

* - Lagoon sludge was cleaned out

References

1. "Energy Production and Use at Sharp Ranch, Tulare, CA", prepared for the California Energy Commission, June 30, 1994, Resource Conservation Management, Inc., Berkeley, CA

2. "Operational Monitoring Data, Sharp Ranch, Sept. 1994 - October 1995", prepared for the California Energy Commission, December 1995, Roy Sharp, Sharp Ranch, Tulare, CA

IX. Regulatory Impact on the Development of Biogas Facilities on California Dairy Farms

Introduction

Rules and regulations set forth by public agencies may impact the use of biogas energy facilities on dairy farms. Since biogas generation is a process of anaerobic digestion of animal wastes, regulations governing animal waste management practices on dairies are the focus of this Chapter. This Chapter will examine existing rules for dairy waste management and their impact on present and future biogas energy project development on California dairies.

Regulations impacting livestock waste management are grouped into three categories: federal laws, state laws and county requirements. Federal environmental laws usually define national minimum standards. Any State may design additional laws and regulations given that the federal standards are met. County requirements are usually designed by zoning, planning or local health agencies.

Federal Laws

Two major federal statutes affecting large dairy operations are the Clean Air Act Amendments of 1977 and 1990 (CAAA) and the 1987 amendments to the Clean Water Act (CWA). Both statutes required the United States Environmental Protection Agency (USEPA) to promulgate standards for industrial air emissions and waste water discharges into surface waters. They are often the basis for the States to establish their own rules. The Coastal Zone Act Reauthorization Amendments of 1990 on the other hand, may have greater significance for dairy operations since they address nonpoint water pollution sources, including large and small farms.

A. The Clean Air Act Amendments (CAAA)

Under court orders, the California Environmental Protection Agency has drafted the Federal Implementation Plan (FIP) to promulgate the CAAA of 1977. Part of the goal of the FIP is to control ozone emissions. Since dairies were considered sources of volatile organic compounds (VOCs), methane and ozone emissions, dairies of 400 or more mature cattle were initially included in this plan. The plan set deadlines for these farms to find ways to reduce their gas emissions. One major recommendation in the plan was to use anaerobic digesters to treat animal waste before its disposal. During field tests by the California EPA in early 1995, however, no significant VOCs were found to be released on farms.

In April of 1995, the California State Implementation Plan (SIP) was adopted by the California Air Resources Board (CARB) and has been implemented by California's Air Quality Management Districts. Concurrent with the adoption of the State Implementation Plan, the FIP was eliminated by the US Congress. Although the SIP has been in place since 1995 and will be approved by the USEPA, it does not contain measures related to ozone control on California dairies. The outlook is that dairies in California will not be subject to air emission regulations pertaining to ozone in the near future.

The original FIP by the USEPA was the only proposed regulation that addressed air pollution by dairy farms, and considered the use of anaerobic digestion technology as one of the potential control measures. With the rejection of the FIP, it is unlikely that the biogas industry can depend on public environmental policy as a driving force for its development in the near future.

B. The Clean Water Act

The 1987 amendments to the CWA established the framework for regulating municipal and industrial storm water discharges under the National Pollutant Discharge Elimination System (NPDES) program. The NPDES defines point sources and requires them to obtain NPDES permits. A point source generally is a source that has a pollutant discharge point clearly defined. Confined animal operations are identified as point sources under the CWA. The affected dairy operations are described as having 700 or more mature dairy cows (whether lactating or dry) and:

1) Having stall barn (with milk room), or
2) Having freestall barn (with milking center), or
3) Having cow yards (with milking centers).

The CWA guidelines state that there shall be no discharge of manure or manure contaminated process wastewater pollutants to navigable waters. The wastewater shall be contained in a structure(s) that has the capacity to prevent overflow during a 25-year, 24-hour rainfall event. Discharge is allowed if the storm exceeds such a magnitude.

The guidelines also require that dairy process water discharging directly into any publicly owned water treatment facilities must contain dissolved oxygen based on 5-day biological oxygen demand tests.

Since California was given authority to issue NPDES permits by the USEPA, the guidelines regarding the CWA are left for the State to enforce. Furthermore, Congress had enacted Section 319 of the CWA that required the States to address nonpoint source pollution. This will be discussed in the state programs section.

One of the most profound impacts of the CWA on dairy operations is its storm water storage requirement. This requirement has contributed to the widespread use of animal waste holding ponds or lagoons. With the successful demonstration of covered lagoon digesters on several swine farms in California, these waste storage installations have become potential sites for biogas system installations. From that perspective, the CWA has established a good base for the application of anaerobic digestion lagoon technology on California dairies.

C. Coastal Zone Act Reauthorization Amendments of 1990

Under the requirement of section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990, the USEPA had issued the *Guidance Specifying Management Measures For Sources of Nonpoint Pollution in Coastal Waters*.

Nonpoint sources of water pollution are generally sources that are not subject to regulation under the NPDES program. Unlike point source pollution which has a clearly defined discharge point, nonpoint source pollution generally results from land runoff, precipitation, storm drainage and seepage. The Guidance has therefore a greater impact on the dairy operations in California than the CWA, since most dairies are in the nonpoint source category.

The Guidance defines a confined animal facility as (p. 2-34):

1) Animals (other than aquatic animals) have been, are, or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12-month period, and
2) Crops, vegetation forage growth, or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility.

Management measures in the Guidance for facility wastewater and runoff from dairies are summarized in Table 9.1 (p.2-33, p.2-45):

Table 9.1 Measures for Two Types of Nonpoint Source Dairies.

Head	Animal units	Measure 1	Measure 2
70 or more	98 or more	Storage for up to & including a 25-yr., 24-hr frequency storm	Manage stored runoff and accumulated solids from facility through an appropriate waste utilization system
20-69	28-97	Minimize discharge of contaminants for up to & including a 25-yr., 24-hr frequency storm, using solids separation basins, vegetative practices, &/or runoff reduction	Manage stored runoff and accumulated solids from facility through an appropriate waste utilization system

This federal Guidance will have a similar positive impact on the development of biogas systems as does the Clean Water Act Amendments. It will encourage the installation of waste storage facilities on smaller dairy farms, which could potentially be developed into lagoon digesters for biogas generation.

California Laws

California was given authority by the USEPA to issue NPDES permits to point source dischargers. The State also has its own environmental laws that are generally more stringent than federal laws including: The California Code of Regulations, the Porter-Cologne Water Quality Control Act and the State's Nonpoint Source Management Plan. They all have significant impact on waste management practices on California dairies. On the other hand, the State has been inclined to find ways to help farmers to meet the discharge requirements by identifying " best management practices," meaning that farmers are encouraged to implement the recommended practices on a voluntary basis as conditions for the waiver of the environmental requirements (Brown, 1994). This approach is reflected in the " Three Tier" process implemented by the California Water Resources Control Board. A further explanation is given in the section under " California Water Resources Control Board."

A. California Code of Regulations

California Code of Regulations Chapter 15 of Title 23 sets minimum standards for discharges of animal waste at confined animal facilities. The California legislators in this case bypassed the California Environmental Protection Agency and set specific requirements in their own regulations. The Code states that these standards must be followed under any waste discharge permits issued for a particular facility or made a condition to the waiver of a permit.

The Water Quality Plans designed by the Regional Water Quality Control Boards have to contain these standards (Richter, 1994). Several important elements of these requirements are summarized below:

a. Animals at a confined animal facility shall be prevented from entering any surface water within the confined area.
b. Confined animal facilities shall be designed and constructed to retain all facility wastewater generated, together with all precipitation on and drainage through, manured areas during a 25-year, 24-hour storm.
c. All precipitation and surface drainage outside manured areas shall be diverted away from manured areas unless such drainage is fully retained. Some exceptions can be made by regional boards.
d. Retention ponds and manured areas shall be protected from washout against 20-year peak stream flows for existing facilities and 100-year peak stream flows for new facilities.
e. Retention ponds shall be lined with soils containing at least 10% clay and not more than 10% gravel or materials of equivalent impermeability.
f. Application of manure and wastewater to disposal fields or crop lands shall be at rates which are reasonable for crop, soil, climate, special local situations, management system and type of manure.
g. Discharge of wastewater shall not result in surface runoff and shall be managed to minimize percolation to groundwater.
h. Manured area shall be managed to minimize infiltration of water into underlying soils.
i. Regional boards may require a monitoring program as a condition to the issuance or waiver of waste discharge requirements.

The impact of these State regulations are similar to that of federal laws. Manure storage ponds can be converted into anaerobic digesters, therefore, the mandatory use of manure storage facilities is a positive step toward on-farm biogas systems development.

B. Porter-Cologne Water Quality Control Act

The Porter-Cologne Act establishes the organization, membership and some of the duties of two state water quality control agencies. They are the California Water Resources Control Board (the state board) and the California Regional Water Quality Control Boards (the regional boards). The duties of these two agencies are outlined below as they relate to the management of waste water on dairies.

California Water Resources Control Board

The state board is designed as the state water pollution control agency for the purposes stated in the federal CWA and other federal acts. It also formulates, adopts and revises general procedures for the regional boards to establish their water quality control plans.

The state board is in charge of issuing NPDES permits in the State. Although dairies with 700 or more adult cows are subject to NPDES permitting, very few of them are required by the state board to obtain the permit. This is the result of a shortage of man power at regional boards to process applications, and also the approach taken by the state board not to mandate permits but to help farmers meet the environmental goals on a voluntary basis (Cosentini, 1994). The later is explained in the state board's " Three Tier" process for getting land users to solve water quality problems. These steps include:

a. Voluntary: Farmers are encouraged to initiate their own solutions to eliminate or reduce the waste runoff and infiltration to surface and groundwaters with the help of the federal and state technical support agencies. If the regional board finds that the effort is made in good faith and the reduction in water pollution is significant, the farmer may be exempt from obtaining a NPDES or other waste discharge permits.

b. Semi-regulatory: If the control of the waste contamination is unsatisfactory, the regional board may impose partial requirements such as setting up a waste disposal monitoring program at the expense of the land owner until improvements are made.
c. Regulatory: If the land owner or the operator is found to be uncooperative, or is repeatedly in violation of waste discharge requirements, he will then have to apply for a NPDES or other waste discharge permits. If not approved, he will not be allowed to operate his facilities.

This " Three Tier" approach essentially takes the pressure to comply with storm water management regulations off the dairy industry in California. The result is less emphasis on waste management on dairies, and a disincentive to the widespread use of anaerobic digestion technologies, on farms.

California Regional Water Quality Control Board

There are nine regional boards that have jurisdictions over twelve areas covering the State. These regional boards have the greatest involvement in monitoring waste disposal activities on California dairies. Several important responsibilities of regional boards is contained in Chapter 4 of the Porter-Cologne Act:

a. Each regional board shall formulate and adopt water quality control plans for all areas within the region.
b. The regional boards shall not adopt any water quality control plan unless a public hearing is first held, after the giving of notice of such hearing by publication in the affected counties.
c. A water quality control plan, or a revision thereof adopted by a regional board shall not become effective unless and until it is approved by the state board.

The regional boards may choose to design their own requirements that go beyond the state board's guidelines. They are also given the authority to investigate, inspect, monitor and hold hearings on any facility described in the Porter-Cologne Act (dairies with 20 or more adult cows, for example). Many have proposed projects designed to improve water quality in areas within their own jurisdictions.

With respect to dairy operations, all owners or operators are required (in theory) to submit a detailed waste discharge plan to the regional boards. These plans are reviewed against regional water quality control plans and used as waivers of the requirements set forth by the state or regional boards, given that such waivers are not against public interests. These waivers may be terminated at any time if the information provided by the owners and operators are found inadequate or in violation of the guidelines. The regional boards will then draft their own versions of requirements on a case by case basis. In reality, however, not all regional boards have their own water quality control plans designed to address the dairy industries in their regions. This is especially true in some coastal and high sierra regions where dairy operations are very few, and in Southern California where water and land are scarce, making proper disposal of animal waste infeasible. On the other hand, several other regional boards have designed their own dairy plans or proposals to address the high concentration of dairy operations in their regions. Dairies in these areas are subject to additional requirements whereas those in the other regions only operate according to state guidelines. Two plans specific to dairy operations in the Central Valley region and Santa Ana region are presented in Appendix C. The general guidelines used by the regional boards to develop water quality control plans are presented below:

General Order of Discharge Requirements

An order of discharge requirements issued by a regional board usually contains the following (Rohrbach, 1994):

a. Prohibitions: General requirements in pursuit of state guidelines and the regional board plan.
b. Discharge specifications: Discharge requirements for the designated dairy.
c. Facility design and operation specifications: Requirements for the design, construction, operation and monitoring of retention pond, flood protection and waste disposal applications, etc.
d. Standard provisions: Duty to comply, entry and inspection, civil monetary remedies, corrective action, etc.
e. Reporting and record keeping requirements: Annual reporting, maintenance of records, permit revision, change in discharge or ownership, etc.
f. Monitoring provisions: Visual monitoring, groundwater sampling (annual or semiannual), etc.

Normally, the regional boards where dairies are more concentrated have more complete water quality requirement plans specifically addressing dairy operations. The concept of biogas systems installation will be more acceptable in these areas, as the pressure to abate the environmental impact of dairy operations is higher.

C. Nonpoint Source Management Plans Developed under the Clean Water Act

The Clean Water Act was amended in 1987 to include Section 319 entitled "Nonpoint Source Management Programs." This section requires the States to develop Assessment Reports and Management Programs. The State's Nonpoint Source Management Plan was initiated by the State Board in response to this requirement.

Ten different Technical Advisory Committees (TACs) were established to review the Plan. Some of the TACs recommendations were based on the Guidance issued by the USEPA (see earlier section entitled "Coastal Zone Act Reauthorization Amendments of 1990"). In January 1995, the TACs submitted their reports at the workshop held by the state board members. The TAC on confined animal facilities (CAF) had basically endorsed the CAF measures suggested in the Guidance. Representatives of the dairy industry addressed their concerns and suggested the following changes to the requirements (TAC, 1995):

a. The management measures shall uniformly apply to all dairy sizes rather than two different ones (refer back to Table 9.1.).
b. Storage capacity for up to and including an equivalent of a 25-year, 24-hour storm in a series of storms rather than a single storm of such magnitude.
c. The management measures should take a "Watershed Approach," meaning that farmers of one geographic area should be organized into one watershed group and work together to solve local problems.

If these suggestions are adopted, they may impact farmers' decisions on installing biogas energy facilities on dairies in both ways. For example, the re-defined storm capacity may lessen the emphasis on the need for preventing wastewater runoff, thereby making biogas facilities less attractive as a means to treat the effluents, since more wastewater will be allowed to overflow without proper treatment. On the other hand, the suggested watershed group approach may make it easier for farmers as a group to get support in constructing biogas facilities.

County Requirements

Some counties have their own rules that will impact dairy operations. These requirements reflect local needs and are sometimes very specific. Owners may be required to submit additional applications or information to local offices such as planning and land use, or the Department of Environmental Health. However, these additional applications are sent to regional boards for approval after being reviewed at the county offices.

Several county ordinances and requirements are presented in Appendix C. They are specific to waste management on confined animal facilities. Counties with such ordinances usually have very concentrated dairy operations and are ideal locations for biogas project development.

Discussion

Federal environmental laws requiring the control of wastewater runoff from dairies and federal policies encouraging reduction of greenhouse gas emissions act as incentives for the development of biogas projects on California dairies.

California environmental laws tend to go one step further than the federal statutes in addressing environmental problems. But because of concerns from the dairy industry, the State environmental agencies are less inclined to impose stringent requirements on California dairies before exhausting more conciliatory means. This takes some pressure off the dairies for considering biogas facilities as a means of environmental protection.

The local ordinances generally encourage biogas development for health and aesthetic reasons. Furthermore, the "Watershed Approach" concept suggested by the Technical Advisory Committee on confined animal facilities also emphasizes local efforts in solving environmental problems. By organizing local farmer groups in solving waste management problems the "Watershed Approach" might also be an effective way of promoting the development of biogas projects on California dairies.

In areas of high dairy concentrations, development of regional biogas facilities as a means of mitigating waste management problems may also be feasible, particularly in areas where markets have been developed for the sale of byproducts of the anaerobic digestion process.

Conclusion

From the overview given it is clear that there are a number of laws and regulations that govern how dairy farms manage their waste storage and disposal in California. For example, federal regulations mandate the use of waste storage lagoons to control stormwater runoff on dairy farms. As a result, waste storage lagoons are commonly used on California dairies. These lagoons are potential sites for biogas system installations. However, there are no regulations mandating the use of technologies such as anaerobic digestion of animal manure to reduce the environmental impact of dairy operations.

The rules and regulations governing ways dairies manage their animal waste are designed mainly to protect surface and groundwaters, sometimes taking public nuisance laws into consideration. No governmental incentives or regulatory mandates currently exist to promote the development of biogas energy projects on California farms. In order for such projects to proliferate at this time, they need to be economically profitable without relying on any regulatory assistance.

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X. Conclusions and Recommendations

Overall Conclusions

Anaerobic digestion technology is available to produce and recover biogas from California confined animal facilities. Three commercial scale technologies are available and have been operated successfully in California: covered lagoons, complete mix digesters and plug flow digesters. Biogas can be used to produce energy on farm to substitute for purchased energy. The technology can be profitable for many farms if : 1) the system capital costs are controlled, 2) the system is user friendly, with reasonable operating costs and 3) a farm is allowed to realize the full market value of energy produced from biogas. Further benefits to a farm from a digester installation are manure odor reduction, manure pathogen reduction and potentially byproduct recovery and sales.

Many barriers exist to increased use of anaerobic digestion technology that can all be traced to a history of poor performance of many units installed in the state. The successful systems have not canceled the effects of failed systems. Therefore, farm owners, financial sources and regulatory agencies have been reluctant to participate in new systems. Minimal concern from governmental agencies and farm owners for proper manure management has limited any driving force for consideration of anaerobic digestion in a manure management system.

Strategies to Overcome Barriers

Education of farmers, bankers and governmental decision makers is the only way to overcome the negative image barrier of anaerobic digesters. It should be pointed out that there are hundreds of municipal and industrial digestion systems operating daily in California. The successful agricultural systems should be promoted as educational tools.

In the future, California farms will probably come under pressure to comply with environmental regulation in the same way farms in North Carolina, Texas, Oregon, Washington and Idaho have recently had to begin compliance. During that time, farms will have to consider anaerobic digestion and methane recovery as manure management options.

Some governmental support of the technology is needed to overcome the initial capital cost barrier. Cost sharing and low interest loans can be used to introduce more successful digester systems to acquaint more farmers with the technology. Bankers need a better track record so that they can loan on the revenue stream of the digester systems.

Utility barriers will only be dropped through societal pressures or economic incentives. In England, there is a national "Non-Fossil Fuel Obligation" where developers bid for electric production capacity and may sell electricity to a utility at rates adequate to profit on their investment. The English have agreed that these energy alternatives are important and pay to support them.

If a utility is offered an incentive and a chance to derive value from a methane production and recovery system, the utilities will promote the technologies with favorable rates and rate structures.

Sulfur dioxide emission credits are valuable commodities exchanged in the open market, allowing utilities to recover value for their investments in SO_2 control. Similarly, if methane emission control through conversion to CO_2 is environmentally beneficial, as stated by President Clinton in the *Climate*

Change Action Plan in 1993, then a utility should be able to claim a tax or pollution credit for every unit of methane recovered from animal manure and burned.

CO_2 control credits are being promoted, however they currently have no value. A pound of methane converted to CO_2 should be worth about 21 times the value of a pound of CO_2 control based on the relative photoreactivity of the two compounds. These credits and their value are political and social issues to be addressed in reducing the utility barrier to on farm electricity generation.

Future Research and Development

Methane Production

Research and development on methane production technology is not expected to yield any breakthroughs that will significantly reduce the annual cost of digester ownership and operation. Most research is focused on increased digester efficiency and reducing digester volumes to reduce costs. Appendix F includes discussion of current research in anaerobic digestion techniques. However, the more efficient units may have significant operation and maintenance costs not found in existing digesters.

Gas Use

There is no university research in progress on improving biogas utilization technology. Private and federal researchers are working on improved efficiency in electricity production using fuel cells, small gas turbines, and Sterling engines. These technologies may be appropriate in farm scale systems some day. However, the current low value paid for electricity exported from a farm would not result in profitable, high efficiency electricity production on farms. Appendix G includes discussion of the current status of these technologies.

XI. Appendices

Appendix A. California Dairy Types

The unpublished South Valley Study was conducted by Mark Moser for the US EPA in 1991. The study described three typical dairy manure collection methods in the South Valley region of California.

Dairy Type - Freestall Flush Dairy

A freestall flush dairy generally includes a milking barn and separate roofed freestall barns for the milking cows. A freestall allows the cow to enter and leave by choice. California freestall barns generally do not have sidewalls. In general, two flushed feedlanes are built opposite each other across a road where a feed truck delivers feed to the cows. Behind the feedlane is usually a double row of freestalls on either side of a flushlane.

Most freestall flush dairies also have drylots for cow lounging. In dry weather the gates to the drylots are generally left open. However, if the weather is hot, cows stay in the freestall barn.

Manure Collection

Barns and flushlanes are sloped at about 1% to enhance the flush water cleaning. Cow traffic lanes are also flushed. The center road does not allow cow traffic and receives no manure.

Flush water source is most often recycled lagoon water mixed with parlor washwater. Flushing with all fresh water or solely recovered parlor wash water is known but not common. Flush lanes are water flushed 2 to 5 times per day. 1200 to 1800 gpm are released at the upper end of the flushlane for as long as necessary to flow down the length of the barn and remove manure. Flush water containing manure is collected at the end of the flush lane and piped either to a separator or to the storage lagoon.

Manure Handling

Most freestall flush dairies have solids separators to recover manure solids for cow bedding in the freestalls. The separators may be either gravity basins or inclined screens. Remaining liquids flow to the lagoon.

Dairy Type - Flushed Drylot Dairy

A flushed drylot dairy has a milk barn and drylots with flushed feedlanes. In general, two feedlanes are built opposite each other across a center road where a feed truck delivers feed to the cows. The drylot for cow lounging is immediately behind the feedlane. A shade structure is often built in the drylot for cows to lie in the shade. The shade may or may not be adjacent to the feedlane and the shade roof may cover the feedlane.

Manure Collection

Feedlane Manure. Manure is flushed from the feedlanes to a lagoon several times a day. The flush water source is either parlor washwater or recycle flushwater. Flushing is designed and operated as described above.

Solid Manure. A significant portion of the manure is deposited in the drylots and subsequently hand as a solid. Drylots are scraped at random intervals as determined by the dairy owner.

Manure Handling

Flush manure liquids are accumulated in a lagoon and held until applied to a field crop. Some flushed drylot dairies have solids separators to keep solids from building up in the main lagoon. The newer dairies are the more likely to have a gravity separator. Drylot solids are often scraped into piles and left until there is an opportunity to haul and field spread or sell the manure.

Dairy Type - Scrape Freestall Dairy

A scrape freestall dairy is generally similar to the description for a flush freestall dairy. Many of the scrape dairies are older dairies located in northern and coastal zones.

Manure Collection

Liquid manure. Only a small portion (10-15%) of the total daily cow manure is collected in the milking parlor along with the parlor washwater. The washwater is piped to a separator or lagoon.

Solid Manure. Manure is scraped off concrete floors with a tractor on a daily to weekly schedule. Manure is pushed into a manure storage or manure spreader.

Manure Handling

Most dairies store manure and parlor process water until it can be properly applied to cropland.

Dairy Type - Drylot Dairies

Most drylot dairies are older dairies. 85-90% of the manure is managed by dry scraping and truck removal. A drylot dairy generally has a milk barn, corrals with paved feedlanes, a drylot and a roofed shade area in the drylot for cow lounging. Drylot feedlanes usually do no have curbs and are not cleaned by flush water. They are most often built with a slope away from the feed lane toward the corral. As there is no need to organize the corrals around a flush water flow, the layout of a drylot dairy can vary according to the needs of the owner.

Manure Collection

Liquid manure. Parlor process water is piped to a separator or lagoon.

Solid Manure. Feedlane manure is scraped into the corral daily, weekly or monthly depending upon the owner. Corrals are scraped at random intervals as determined by the dairy owner. The solids are often scraped into piles and left until there is an opportunity to haul and field spread or sell the manure.

Manure Handling

Parlor process water is usually accumulated in a lagoon and held until applied to a field crop. Some drylot dairies will apply parlor process water directly to an application field

Drylot solids are often scraped into piles and left until there is an opportunity to haul and field spread or sell the manure.

Appendix B. Source Information and Biogas Production Calculation

The South Valley Study.

The unpublished South Valley Study was conducted by Mark Moser for the US EPA in 1991. The study described three typical dairy manure collection methods in the South Valley region of California. These collection techniques were based on the dairy housing patterns and manure deposition characteristics for each dairy type. The study estimated biogas generating potentials for these three types of dairies in the region.

South Valley area of California contains the largest milk cow population of any region in the US. The availability of irrigation water in the area has allowed the development of water based flushed systems to remove manure from the dairies into lagoons for disposal.

The South Valley dairies tend to manage their animals in very similar ways. The most notable difference between dairies is in cow housing. Manure management is relatively similar among dairies with similar cow housing situations. They can be grouped into three dairy types:

1. Flushed freestall
2. Drylot with feedlanes flushed
3. Scraped drylot

The estimated distribution of different dairy types in the region is: freestall flush--25%; flushed drylot--66%; scraped drylot--9%.

In the *South Valley Study*, the dairies in the South Valley region were grouped into the three types listed above based on their manure collection methods. Dairy facilities are built in response to predominant annual climate/rainfall conditions and local situation, such as topographical condition. Flushed freestall dairies and drylot dairies with feedlanes flushed are common in the areas where agricultural water supply is adequate and crops need to be irrigated, such as the South Valley region. Scraped drylot dairies are often located in desert areas in Southern California. Conversely, in the Northern California regions, there are a significant number of dairies that use scraped freestall barn and drylot waste management techniques due to the wet winter conditions.

Table 1 is a summary of potential methane emission from lagoons under current waste management practices. Assumptions to support the table are described later in this appendix.

Table 1. Summary of Potential Methane Emission from Lagoons at Prototype Dairies.

	Methane production (CH_4 ft^3/Animal Unit [a])		
	Flushed freestall	Drylot with feed-lanes flushed	Scraped drylot
Without separator	29	21	4
After Screen separator[b]	23	17	3
After Gravity separator[c]	17	11	2

a. One Animal Unit is the equivalent of an animal of 1000 lb.

b. Assuming separator recovers 25% of volatile solids.

c. Assuming separator recovers 40% of volatile solids.

California Dairy Cost Analysis

The California Dairy Cost Analysis is an on-going task of the California Department of Food and Agriculture (CDFA) to analyze and update the cost of milk production in California. The analyses are conducted by Walt Spivey and his office staff at the Milk Stabilization Branch. Hundreds of dairies in California are part of this continuing study, providing CDFA the entire inventories of their dairy operations on a voluntary basis. The data is used for dairy cost estimates in an effort to offer better marketing strategies for the California dairy industry. A portion of the data contains information on the manure collection methods and cow housing of the participating dairies.

The CDFA provided 1994 dairy housing and manure collection information for all 336 participating California dairies. The information includes the number of dairy cows and the type of manure collection. The dairies are not identified, rather numbered in the order of information received to keep the names of the dairies confidential. The manure collection methods represented in the records are of three standard types: flushed freestall, drylot with feedlanes flushed and scraped drylot. The manure management techniques identified by the CDFA are the same as in the *South Valley Study*. The difference is that the 336 dairy records in the CDFA study cover all regions of California, with greater numbers of records collected in the regions where dairy operations are more concentrated. Table 2 is a summary of this information. It is apparent that climate in combination with the availability of water and land for liquid application determines the manure collection methods used in each region. For example, dairies in Southern California are almost all of the scraped drylot type due to the lack of land. All three dairy types exist in the South Valley region with the older dairies being mostly of the scraped drylot variety.

California Dairy Industry Statistics.

The CDFA's annual report of dairy industry statistics summarizes the vital dairy statistics of the past year and predicts the changes for the coming year. The most updated report available was published in 1994, and estimates the number of milk cows in California by county and district. These numbers are summarized in Table 2 and are used to estimate the overall methane production potential on California dairies. The data is grouped in the six dairy regions identified in the California Dairy Cost Analysis as well as in the *South Valley Study*. Figure 4.1 in Chapter 4 illustrates where these six regions are located in California.

Table 2. Types of dairies in the records from the Milk Stabilization Branch of the CDFA.

Dairy type	All Dairies		Flushed freestall			Drylot with feedlanes flushed			Scraped drylot		
Region	# of dairies	# of cows in total	# of dairies	# of cows	% of total cows	# of dairies	# of cows	% of total cows	# of dairies	# of cows	% of total cows
North Bay	27	9,166	18	6,704	73.14%	0	0	0.00%	9	2,462	26.86%
North Coast	12	2,315	4	1,281	55.33%	0	0	0.00%	8	1,034	44.67%
North Valley	118	64,666	41	28,192	43.60%	0	0	0.00%	77	36,474	56.40%
Sacramento Valley	30	8,006	7	2,907	36.31%	0	0	0.00%	23	5,099	63.69%
South Valley	97	86,175	31	30,090	34.92%	42	45,680	53.01%	24	10,405	12.07%
Southern California	52	45,826	0	0	0.00%	6	5,630	12.29%	46	40,196	87.71%

Table 3. Number of milk cows in California, 1994.

North Bay		North Coast		North Valley		Sacramento Valley		South Valley		Southern California	
County	# of cows	County	# of cows	County	# of cows	County	# of cows	County	# of cows	County	# of cows
Contra Costa	2,168	Del Norte	1,176	Madera	20,456	Butte	1,219	Fresno	66,633	Imperial	626
Marin	13,195	Humboldt	14,822	Merced	138,388	Colusa	407	Kern	33,448	Los Angeles	1,975
Monterey	3,342	Mendocino	837	San Joaquin	75,453	Glenn	14,689	Kings	91,156	Riverside	122,277
Napa	317	Shasta	664	Stanislaus	129,519	Sacramento	17,622	Tulare	232,674	SB[b]	163,215
San Benito	713	Siskiyou	2,030			Solano	1,506			San Diego	7,808
SLO[a]	436					Sutter	666			Santa Barbara	2,322
Santa Clara	1,073					Tehama	3,041				
Santa Cruz	298					Yolo	619				
Sonoma	31,065					Yuba	2,419				
Total	52,607	Total	19,529	Total	363,816	Total	42,188	Total	423,911	Total	298,223

a. San Luis Obispo.
b. San Bernardino.
Source: *California Dairy Industry Statistics 1993*, California Department of Food and Agriculture.

Assumptions Included in Development of Methane Potential

The many uncertainties involved in collecting data on farms make an assessment of methane production potential difficult. Therefore, some assumptions were made in this study. The major assumptions are explained in detail below.

I. Typical Waste Management Techniques on Dairies in California.

The 336 dairy records provided by the Milk Stabilization Branch of the CDFA categorize California dairies into the same three waste management groups used in the *South Valley Study* and described in Appendix A. It is assumed that manure collection methods on California dairies are directly related to the availability of water and agricultural land in the regions and the prevailing weather patterns.

II. Methane Production Potential for Each Dairy Type.

In the *South Valley Study*, the methane emission potential per animal unit was estimated for each dairy type in the region, as stated in Table 1. These estimates were used directly in this study to assess the methane production potentials on dairies of the same type in other regions of California. The basis for this generalization is: 1) The dairy types described in the *South Valley Study* are typical of dairy types found in California, as seen from the dairy records of the CDFA milk stabilization office; and 2) Methane generating potential is directly related to waste collection technique which depends on dairy type.

III. The Representativeness of the 336 Dairy Records.

The 336 dairy records provided by the CDFA Milk Stabilization Office cover all six dairy regions in California. The data provided for the South Valley region compares favorably with the estimates in the *South Valley Study*. Table 4 compares data from these two sources. It is therefore reasonable to assume that the CDFA data also provides a good estimate of the distribution of dairy types in the other five California dairy regions.

Table 4. Comparison of Dairy Type Distributions in South Valley Region.

Dairy type	South Valley Study	CDFA data
Flushed freestall dairies	25%	35%
Drylot with feedlanes flushed	66%	53%
Scraped drylot dairies	9%	12%

IV. Dry Cows and Heifers.

Dry cows and heifers are often managed in drylots and young stock may not be raised on the same farm. Furthermore, the number of dry cows and heifers were small and their turnover time was short. Therefore the impact of dry cows and heifers on the methane generation potential is considered to be negligible. The number of animals in the 336 dairy records and the CDFA's *Dairy Industry Statistics* report were used directly in this study.

V. Assumptions for Calculation of Manure and Methane Yields

Estimates of biogas production are based on the assumption that under current manure collection practices, all flush manure systems have solid separators to prevent lagoon fouling, and lagoons could be covered to capture methane.

The calculations in the next section are based on the following assumptions:

1. An average dairy cow weighs 1,400 lbs and produces 120 lb/d of manure containing 11.33 lb of volatile solids.
2. Manure is collected within 2 days of deposition.
3. 1 lb of 2 day old volatile solids from a dairy cows anaerobically digests to produce 3 ft^3 of methane.
4. The percent of manure collected by farm type is: 90% on flush freestall dairies, 60% on flushed feedlane dairies and 15% on drylot dairies.
5. Solids separation reduces biogas production potential by 25%.

Calculation Method

The CDFA data provides a sample distribution of dairy types in California in 1995. This distribution was applied directly to the *California Dairy Industry Statistics* data, and an estimate of the number of cows in each dairy type was obtained statewide. The methane emission potentials developed in the *South Valley Study* were then applied on a per animal unit basis for each dairy type to obtain an estimate of the statewide methane generation potential from dairy manure. The methodology recognized that different waste management practices result in different *methane generation potentials*.

Results

I. Biogas Potential on California Dairies.

Besides the difficulty of counting animals on dairies and estimating manure deposition patterns due to the seasonal weather variations, seasonal variation in methane emission rates make the estimation of biogas potential even more troublesome. Biogas production from an anaerobic lagoon during the summer can be as much as 2 times that in the winter. Mr. Moser has taken these factors into consideration in the development of the methane emission potentials, therefore the methane emission rates for each dairy type in the *South Valley Study* are the annual average figures. Using the same methane emission potentials, Tables 5 and 6 calculate the total daily methane emissions from the lagoons on California dairies. Figures 4.2 and 4.3 in Chapter 4 illustrate the distributions of dairy types and the methane production potentials in relation to the dairy populations for all regions.

Table 5. Numbers of Animals on Each Dairy Type in California.

Region	# of Cows	% share of cows on dairies			Number of cows on dairies		
		F. F.[a]	F. Drylot[b]	S. Drylot[c]	F. F.[a]	F. Drylot[b]	S. Drylot[c]
North Bay	52,607	73.14%	0.00%	26.86%	38,477	0	14,130
North Coast	19,529	55.33%	0.00%	44.67%	10,805	0	8,724
North Valley	363,816	43.60%	0.00%	56.40%	158,624	0	205,192
Sac. Valley	42,188	36.31%	0.00%	63.69%	15,318	0	26,870
South Valley	423,911	34.92%	53.01%	12.07%	148,030	224,715	51,166
S. California	298,223	0.00%	12.29%	87.71%	0	36,652	261,571
Totals	1,200,274				371,254	261,367	567,653

a. Flushed freestall dairies. c. Scraped drylot dairies.
b. Drylot with feedlanes flushed dairies.

Table 6. Daily Methane Production Potentials on California Dairies.

Type of dairies	# of cows	# of Animal Units (AU)[a]	Unit potential CH_4 (ft^3/AU)[b]	Daily potential CH_4 (ft^3)
Flushed freestall	371,254	519,756	23	11,954,388
Flushed drylot	261,367	365,914	17	6,220,538
Drylot	567,653	794,714	3	2,384,142
Totals	1,200,274	1,680,384		20,559,068

a. Animal Unit = 1 animal count × 1.4.
b. Screen solids separators are used.

It is estimated that California dairies have a daily methane production potential of over 20 million cubic feet. Biogas usually contains 60% CH_4 and 40% CO_2 with higher heating value of 22 MJ/m^3, or approximately 600 BTU/ft^3. Therefore, the estimated daily biogas production potential is over 34 million cubic feet. The gross power potential of this biogas resource is 247 megawatts (MW).

Biogas Potential $= 20{,}559{,}068\ (\text{ft}^3/\text{day CH}_4) \div 0.60\ (\text{ft}^3\ \text{CH}_4/\text{ft}^3\ \text{Biogas})$

$= 34{,}265{,}113\ (\text{ft}^3/\text{day Biogas})$

Energy Potential $= 34{,}265{,}113\ (\text{ft}^3/\text{day}) \times 365\ (\text{day/year}) \times 0.0283\ (\text{m}^3/\text{ft}^3)$

$$\times 22(\text{MJ/m}^3) \times \frac{1\text{KW-hr}}{3.6\text{MJ}} \times 10^{-3}\ (\text{MW-hr/kW-hr})$$

$= 2{,}162{,}976\ (\text{MW-hr/year})$

or $= 34{,}265{,}113\ (\text{ft}^3/\text{day Biogas}) \times 365\ (\text{day/year}) \times 600\ (\text{BTU/ft}^3\ \text{biogas})$

$= 7.50 \times 10^{12}\ (\text{BTU/year})$

Gross Power Potential $= 2{,}162{,}976\ (\text{MW-hr/year}) \times \dfrac{1\text{year}}{8{,}760\text{hr}}$

$= 247\ (\text{MW})$

II. Biogas for Electricity Generation.

After proper treatment, biogas can replace fossil fuels to drive natural gas, diesel and gasoline engines on dairy farms. If electric generators are used, the biogas energy can be converted into electric power. If the heat rate of 15,000 BTU/kWh is considered for gas engine-generator systems, and all potential generated biogas were converted into electric power, the potential electric power generation capacity of the biogas resource on California dairies today would amount to 57 MW.

$$\text{Potential Electric Power Generation} = 7.50 \times 10^{12}\ (\text{BTU/year}) \times \frac{1\text{year}}{8{,}760\text{hr}} \times [15{,}000\ (\text{BTU/kWh})]^{-1} \times 10^{-3}\ (\text{MW-hr/kW-hr})$$

$$= 57\ (\text{MW})$$

III. Comparison of Study Results.

Many studies have been done in the past to estimate the renewable energy potential from collectable animal wastes on US farms. In California, dairy farms have always been favorable sites for biogas energy systems because of the high collectibility and energy content of dairy manure. In addition, due to their large numbers, dairies in California have the largest biogas generation potential among all confined livestock farming facilities in the State. But few researchers have taken into consideration the fact that different animal waste management practices result in different manure collection percentages and hence different biogas production rates per animal from the digesters. Furthermore, biogas potentials on confined animal facilities in California were often estimated using the data from national studies, therefore, the impact of the California climate conditions on the methane emissions was not considered.

A report from the Western Regional Biomass Energy Program analyzed the energy potentials of animal manure for 13 western states (WRBEP, 1994). This report used the dairy animal counts in 1993 and concluded that with a 1.15 million dairy population in California, the State had the biogas energy potential of 12,439,267 million British Thermal Units (BTUs) on an annual basis. This is the equivalent of 416 MW of gross power, and 95 MW of potential electric power can be generated from it:

$$\text{Energy Equivalent} = 12{,}439{,}267\ (\text{MBTU/year}) \times 1055\ (\text{MJ/MBTU}) \times \frac{1\text{KW-hr}}{3.6\text{MJ}} \times 10^{-3}\ (\text{MW-hr/kW-hr})$$

$$= 3{,}645{,}396\ (\text{MW-hr/yr.})$$

$$\text{Potential Gross Power} = 3{,}645{,}396\ (\text{MW-hr/yr.}) \times \frac{1\text{year}}{8{,}760\text{hr}}$$

$$= 416\ (\text{MW})$$

$$\text{Potential Electric Power} = 12{,}439{,}267 \times 10^{6}\ (\text{BTU/year}) \times \frac{1\text{year}}{8{,}760\text{hr}} \div 15{,}000\ (\text{BTU/kWh}) \times 10^{-3}\ (\text{MW-hr/kW-hr})$$

$$= 95\ (\text{MW})$$

Table 7. Comparison Of Biogas Energy Estimates On California Dairies.

	WRBEP Study[a]		This Report
Dairy population (1000's)	1,150	1,200[b]	1,200
Potential gross power (MW)	416	433[b]	247
Potential electric power (MW)	95	99[b]	57

a. Data in Western States Study are converted from their original energy estimates.
b. Adjusted estimates using current dairy information.

The WRBEP's estimates are higher than the results in this study due to the generalization in manure handling practices. Furthermore, for practical purpose, this study assumes the use of screen separators to prevent lagoon fouling. The use of screen separators will reduce the biogas yield by 25% due to the separation of some volatile solids in the digester feed.

Conclusion

In the California Energy Commission's *1994 Draft Biomass Resource Assessment Report For California*, livestock manure was identified as the most abundant biomass resource in the State. Among all the confined animal feeding facilities in California, dairies generate the largest amount of manure that can be collected and used for biogas generation. If the biogas resource on California dairies is fully utilized, using anaerobic digesters connected to engine generator sets, it has the electric power potential of 57 MW. This is the equivalent of the annual electric consumption for nearly 50,000 single family homes (assuming 10,000 kWh annual consumption per home). Furthermore, the anaerobic digestion process virtually eliminates pathogens in the effluent, significantly reduces odor on the farm, and generates not only biogas as an energy source but also valuable agricultural byproducts such as the digested solids.

Appendix C. Selected Regional Water Quality Control Plans and County Ordinances

1. Dairy Proposals of Central Valley Region, Tulare Lake Basin

The Central Valley Regional Board has designed its own Dairy Proposals to handle the four dairy counties in the area (Gladden, 1994). The four counties, Kings, Kern, Fresno and Tulare, incorporate the largest dairy operating region in the nation. Some requirements and recommendations set forth in the Proposals are summarized below. They are in addition to the State guidelines.

a. Lagoon capacity: Properly managed dairy waste systems with 120 days of storage capacity. Lagoons shall have freeboard of not less than two feet (measured vertically) and shall be designed and constructed to prevent overtopping due to wind conditions.
b. Lagoon liner: A minimum of one foot of imported soil where natural soil does not meet specifications. One must still demonstrate that pathogenic bacteria in filtration wastewater are adequately treated.
c. Waste load balancing: A little over four animal units per acre is properly balanced for a dairy disposing of waste on double-cropped fields. UC Extension recommends that each volume of wastewater be diluted with three volumes of normal irrigation water.
d. Nuisance: Design lagoons of adequate size for organic loading (120-day holding time). Keep surface scum on and sludge in lagoons to a minimum. Control weeds on the interior slopes of lagoons. Flush out remaining solids with irrigation water or promptly cover remaining wastewater with a layer of fresh water when emptying or drawing down a lagoon. Control burrowing rodent activities on embankments.
e. Separation from supply wells: Minimum separation between wastewater impoundment and irrigation areas and wells used for either domestic supply or irrigation are 500 feet and 100 feet respectively.
f. Monitoring programs.

2. General Waste Discharge Requirements For Concentrated Animal Feeding Operations, Including Dairies, within the Santa Ana Region

The Santa Ana Region is home to two of the largest dairy counties in Southern California, Riverside and San Bernardino Counties. This region's requirements in addition to the State guidelines are:

a. Disposal of manure to disposal land shall not exceed 3 tons (dry weight) or 10 cubic yards (dry volume) of manure per acre per year.
b. An explanation is required in the annual report for manure solids application to cropland above twelve dry tons per acre per year,
c. The discharge of brine waste is prohibited.

3. Summary of "Animal Waste Processing" Requirements, Department of Planning and Land Use, County of San Diego:

a. No animal waste processing operation shall be located closer than 1/2 mile from property in a zone which does not permit animal waste.
b. No animal waste processing operation shall be established or maintained on a lot or parcel unless such lot or parcel is 5 acres or more in area.
c. No structure in connection with the operation of animal waste processing shall be maintained closer than 1,000 feet from the nearest pool, tennis court, public playground or dwelling located outside the boundary of the parcel or contiguous parcels associated with the animal waste processing operation at the time the Major Use Permit is granted.
d. Operational plan shall be submitted in detail.
e. The Director of Public Health shall review all applications and make recommendations thereon, sending a copy of each application to the California Regional Water Quality Control Board for approval.

4. Summary of "Waste Management Plan-Animal Confinement/Poultry Operations," Department of Health, County of Merced.

The following information is required to review an animal confinement/poultry facility proposal in the County of Merced:

a. Animal capacity
b. Facility map
c. Facility operations
d. Groundwater condition
e. Disposal fields or crop land applications
f. Soil conditions
g. Construction details

5. Ordinance No. 3105, Board of Supervisors, San Bernardino County.

Based on this Ordinance, cattle or goat dairies established after November 1969 shall conform to the following requirements in San Bernardino County:

a. Four sets of detailed plans for the proposed dairy shall be submitted for review.
b. Corrals shall have a minimum area of five hundred square feet per cow and 166 square feet per goat.
c. The number of animals on each parcel of land shall not exceed twenty cows or sixty goats per gross acre.
d. A minimum of five gross acres shall be provided for waste disposal and open uses for every two hundred cows or a fractional number thereof. For each additional forty cows, one gross acre shall be provided for waste disposal.

6. Dairy-Animal Confinement Facility Locational Guidelines, Tulare County.

Tulare is the single largest dairy county in California. The County Planning Commission adopted its Animal Waste Management Element as part of the Guidelines in 1974. Staff reports on dairy and feedlot projects are required to set forth whether such guidelines and criteria can be met.

The Element was amended in 1984 by the Planning Commission in its Resolution No. 6105, it is noted that the criteria and policies "are to be considered as guidelines and are not to be interpreted as mandatory requirements." Thus, projects which deviate from these policies may be approved on a case-by-case basis provided that mitigation or other findings are made which justify the deviation. Below are several major criteria in the guidelines:

a. Parcel size: The minimum lot size is 80 acres.
b. Separation between animal raising facilities: Constructed buildings of animal raising facility should be no closer than 1320 feet to buildings of other feedlot operations.
c. "Wet stock" density: The maximum density of "wet stock" (milk cows) animals on a dairy should not exceed six animal units per acre.
d. "Dry stock" density: The addition of a new facility should not cause the maximum density of "dry stock" (dry cows) animals to exceed four animal units per acre unless adequate technologies are provided to prevent pollution.
e. Locational criteria: A new animal facility should not lie within a Windshed Area (one mile set-back from an incorporated or unincorporated community's urban boundary or urban type residential zoning boundary line), nor within open space for areas zoned for urban type uses and containing a minimum of 30 dwelling units, nor within primary floodplains, nor within 1000 feet of the boundary of a public park, in sink holes or areas draining into sink holes, nor within one-half mile of the nearest point of a dwelling structure in a concentration of 10 or more private residences.

7. *Others*

Other counties do not specifically address confined animal facilities in their ordinances. It is assumed that those counties have left such issues for their regional boards to administer.

Appendix D. Safety Considerations for Biogas

Safety Considerations for Biogas.

The major components of biogas are methane (CH_4) and carbon dioxide (CO_2). Another component of concern is hydrogen sulfide (H_2S). Biogas like " manure gas" can be toxic if inhaled directly, corrosive to equipment and potentially explosive in confined space when mixed with air. When properly managed the biogas is as safe as any other fuel such as propane used on the farm. If improperly managed these elements can be very hazardous as has been shown in a number of " manure gas" incidents which injured or killed farmers.

Methane. Potential hazards: asphyxiation, explosion. When collected from a plug flow digester, methane makes up 60 - 80% of the biogas volume. As generated and collected, biogas does not contain oxygen. As collected there is no combustion or explosion hazard due to the lack of oxygen. The piped biogas will not burn until mixed with air. Methane generally does not collect in pits as it is lighter than air. If released in a confined space and diluted to approximately 17 - 23% concentration in air and given a source of ignition, an explosion can occur. If leaked into a sealed or poorly ventilated room displacing air, the lack of oxygen can be harmful to animals and humans. Smoking should be prohibited in areas of biogas collection and utilization.

Carbon Dioxide. Potential hazards: asphyxiation. CO_2 makes up 20 - 40% of the biogas volume. Carbon dioxide is heavier than air and will collect in poorly ventilated pits and confined spaces, while other gases dissipate. CO_2 does not burn or explode. If leaked into a sealed or poorly ventilated room displacing air, the lack of oxygen can be harmful to animals and humans. Entry into pits or confined spaces filled with CO_2 ***may result in asphyxiation.***

Hydrogen Sulfide. Potential hazards: human toxicity, equipment corrosion. H_2S is present in the air of all confined animal feeding operations. It is lighter than air and dissipates rapidly. Very low concentrations corrode steel, iron, aluminum and copper. H_2S makes up 0.1 - 0.3% (1000 PPM to 3000 PPM) of the volume. H_2S can be detected by its " rotten egg" smell in concentrations from 1 - 100 PPM. Direct inhalation of H_2S in concentrations above 10 PPM are harmful to the respiratory tract. Direct inhalation of H_2S above 500 PPM will cause rapid respiratory failure and inhalation of concentrations above 1000 PPM can cause unconsciousness and death.

Appendix E. Data Collection for CMEM Model

DAIRY HERD SIZE

Cows in Milk Herd	______	Rolling herd avg.	________	lb
Milkings per day	______	Milk Production	________	lb/d
No. Milking Groups	______	Group Time in Milk Barn	________	hr

	Population/Location			
	Drylot	Daily Scrape	Flush Feedlane	Flush Freestall
Milk Cows	______	______	______	______
Dry Cows and bred heifers	______	______	______	______
Heifers (1 yr to breeding)	______	______	______	______
Calves	______	______	______	______
Total	______	______	______	______

Access to drylot? ______ y/n ______ hr /d

PIG FARM SIZE

Sows	______
Piglets	______
Nursery Pigs	______
Growing Pigs	______
Finishing Pigs	______

ENERGY USE If you cannot find these values, the program uses a default value

Electricity	______	$/kWh	__________	$/yr
Propane	______	$/gal	__________	$/yr

MANURE COLLECTION - If you cannot find these values, the program uses a default value

Parlor Flush/hose wash	______	times/d	______	flushes/d	______	EST total vol/flush
Feedlane Flush	______	flush valves	______	flushes/d	______	vol/flush valve
Freestall Flush	______	flush valves	______	flushes/d	______	vol/flush valve
Scrape Feedlanes	______	winter times/wk	______	summer times/wk		
Scrape Freestalls	______	winter times/wk	______	summer times/wk		
Scrape Corrals	______	times/mo into corral pile	______	times/yr remove from corral		

CLEANING WATER ESTIMATE- If you cannot estimate a total , the program uses a default value

Hose or High Pressure Wash		________ gal/d
Milk Cooler		________ gal/d
Cow Wash Sprinklers		________ gal/d
Milk System		________ gal/d
Milk Tank		________ gal/d
Milkroom and Parlor Floor wash		________ gal/d
Cow wash		________ gal/d
	TOTAL	________ **gal/d**

MANURE TREATMENT/STORAGE

Solids Separation - If you check yes, the program uses 20% recovery

Gravity Separator ______ y/n
Mechanical Separator ______ y/n
Estimate % Solids recovery __________%

Estimate

Incline bar screen, perforated drag screen	15 - 20%
Shaker screen	20%
Screw press	25%

First Lagoon - Need at least information from first line below

length_______ width_______ depth_______ capacity _______
design minimum depth _______
volume at minimum depth _______
sideslopes ____/__1__
constant volume _________ y/n

Appendix F. Attached Growth Digesters

Attached growth digesters will be discussed here due to current promising research. However, these systems cannot be developed and analyzed due to a lack of design information.

The basic studies of Young and McCarty (1) were largely responsible for early development of the anaerobic filter process. In the 17 years between that report and the summary of Colleran, et al, (2) the process was developed and commercialized to treat food processing wastewaters, wheat starch wastewater, sugar refinery wastewater, and guar processing wastewater.

Since 1983, large numbers of variously configured proprietary attached growth anaerobic filter systems have been commercially installed at food processing plants (France, Florida, Pennsylvania), cheese plants (Iowa, Illinois), pharmaceutical plants, paper plants, landfills (Illinois, Maryland) and breweries (Wisconsin, Puerto Rico). Literature reports are limited due to the commercial nature of the projects.

Several design firms do most of the design work including Biotim (Belgium), Biothane (Netherlands, US), ADI Ltd.(Canada, US), and Aqua-Tec (US). However, these firms work exclusively for large corporations because they do not see any potential profits from working on farm scale systems.

Research on attached growth systems for waste treatment from animal agriculture has been limited and most often directed at swine waste in Europe. Approximately 7 full scale anaerobic attached growth digester systems are operating in Europe. (3)

Hill (4), Wilkie (5) from Ireland, Marques from Portugal (6), and Urbano from Spain (7) reported on bench and pilot scale anaerobic filters treating screened swine waste. All reported bench scale anaerobic filters operated at 35 degrees C with hydraulic retention times of 2 to 6 days and loading rates between 3 and 25 kg VS per cubic meter per day. All researchers reported volatile solids reduction between 40 and 65 per cent, representing an 80 to 90% reduction in degradable organics.

Lo (8) from Canada reported on anaerobic filters treating screened dairy manure. Lo tested a variety of filter materials, operating temperatures and detention times. Lo found volatile solids reductions between 20 and 30% with loading rates between 2.8 and 5.2 kg VS/m^3/day and hydraulic retention times between 6 and 10 days. This represents a reduction of 50 to 75% of degradable volatile solids.

The balance of work to date has been conducted in heated reactors operating at 35° C. The volume of water used in a manure flushing system precludes recovering adequate methane to be able to maintain an anaerobic filter heated to 35° C.

The most useful anaerobic attached growth reactor for flushed manure waste would be one that operated at the temperature of the flush water. Full scale covered lagoon systems have been built to stabilize manure and recover methane. The importance of this work is the continuing operation at reduced temperatures. Safley (9), Chandler (10) and Winrock International (11) have reported on lagoons treating flushed dairy or flushed hog waste operating year round at temperature between 10 and 28° C at loading rates of 0.1 to 0.25 kg VS/m^3/d. These systems have operating volumes between 40 and 70 days of flush liquid volume. 60 to 80% of the volatile solids were destroyed.

Current Research in Attached Growth Reactors

Cal Poly San Luis Obispo has been operating a 700 gallon downflow attached growth reactor for 18 months treating screened dairy flush liquids. The reactor is packed with plastic media and has been operated at very high loading rates with a hydraulic detention time of 2 days or less. The system has reduced influent VS by up to 80% (12)

A Florida dairy has operated a pilot 6,000 gallon horizontal flow, packed attached growth reactor treating settled and screened dairy flush liquids for 6 months. The pilot tank is packed with chipped tires and has a loading rate of .06 LB COD/ft^3/d and a hydraulic detention time of 4 days. There is some concern about potential for solids accumulation. The study results will be reported in 1998. (13)

The University of Florida is constructing an attached growth reactor to treat settled screened flush dairy liquid. The reactor will be filled with wood batting for attached growth and operate in the up or down flow mode. The research proposes to operate a 3 - 6 day HRT system (14).

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Appendix G. Alternative Gas Use Technologies

Steam Turbines (1,2)

Small scale steam turbines require a boiler, turbine-generator, condenser and cooling tower. Steam turbines make sense where a high heat demand can make use of the condenser heat. Typical farms would not benefit from this heat availability. Systems are normally described as operating on 275 psi or higher steam pressure. Operation and maintenance skill is beyond the level normally found on farms. There are very few instances where local service would be available.

The 1990 installed cost of a steam turbine is shown as \$250 - \$500/kW however, this does not include gas handling, gas treatment (optional), a steam boiler, cooling tower or piping.

The major advantage of a steam turbine, if run on a farm, would be its low maintenance costs (\$0.002-\$0.004/kWh)

Combustion Gas Turbines Generator (1,3,4,5)

A combustion gas turbine is a fixed version of a turbojet engine coupled to a generator. The systems typically operate on 150 to 250 psi fuel and large quantities of excess air. Biogas would have to be treated and dried to make a suitable fuel for a combustion turbine. Most of the combustion energy is wasted as exhaust heat. Only about 14% of the input energy can be recovered as shaft power. An exhaust heat steam boiler would be required to make efficient use of available energy.

This is a technology not suited to the skill level of the average farmer. One manufacturer stated that he did not know of a " small" (less than 200 kW) combustion turbine that was commercially available to run on gaseous fuel. Sales and service are not available locally.

Stirling Engines (6,7,8)

A Stirling engine is a very simple machine. Fuel combustion takes place as an open flame in a combustion chamber. Helium is heated and expands to move a piston. Expended hot gas is captured, cooled and " regenerated" in a closed loop cycle. The piston turns a crankshaft which is coupled to a generator.

The engines were developed for modern use in Sweden and brought to the United States for demonstration and testing. The original units were directed at the very small power market (5-15 kW). Unfortunately the US company is no longer in business and commercial units are not available.

One of the original test units was transferred to Sharp Ranch for biogas benchmark testing. The test had intermittent success, however difficulties in operating the Stirling in parallel with the existing Waukesha engine-generator limited the usefulness and applicability of the results.

Fuel Cells (9,10)

Fuel cells offer a future potential for a high efficiency conversion of methane to electricity. The chemical process is estimated to be 50% efficient using low BTU fuels. Gas treatment and drying would be required. There are only military and research applications of fuel cells at this time. A 200 - 250 kW capacity cell is currently being tested at a landfill in Southern California.

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Appendix H. Graphs of Variation of NPV vs. Variation of Factor Value

Figure 1. Freestall Flush Dairy, Covered Lagoon, Variation of Electricity Value

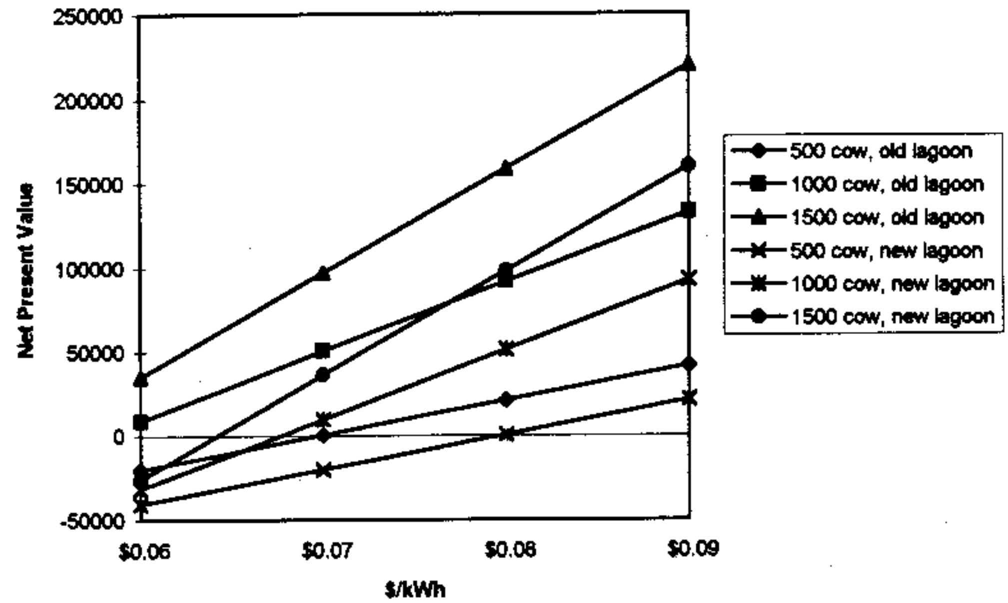


Figure 2. Freestall Flush Dairy, Covered Lagoon, Variation of Capital Cost

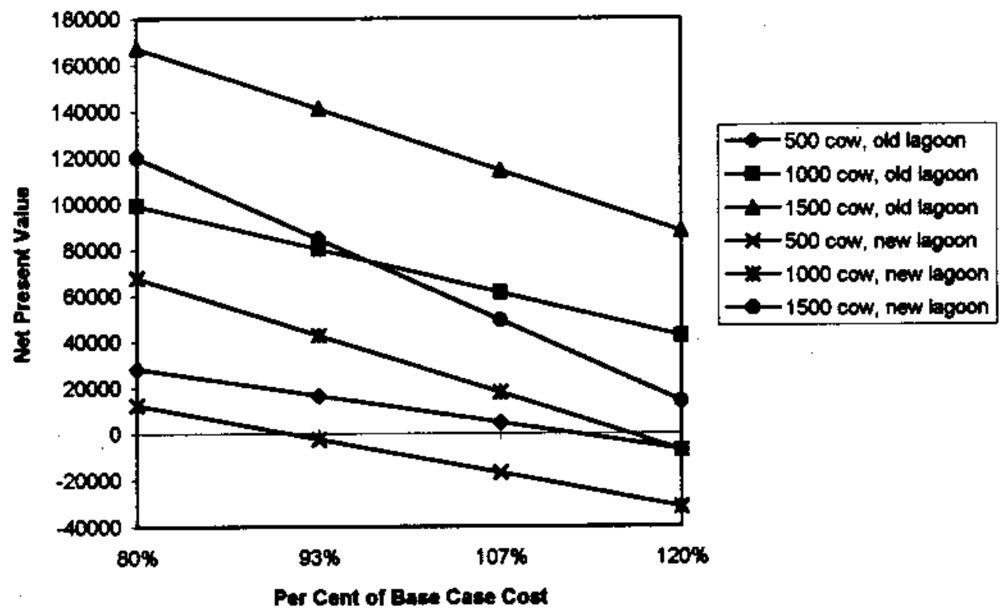


Figure 3. Freestall Flush Dairy, Covered Lagoon, Variation of Discount Rate

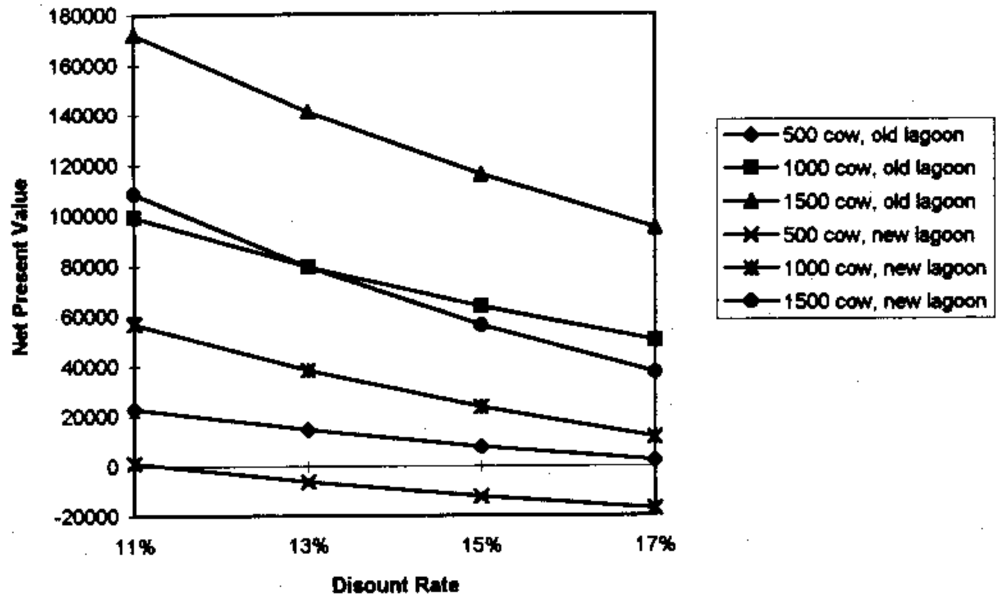


Figure 4. Freestall Flush Dairy, Covered Lagoon, Variation of Loan Interest Rate

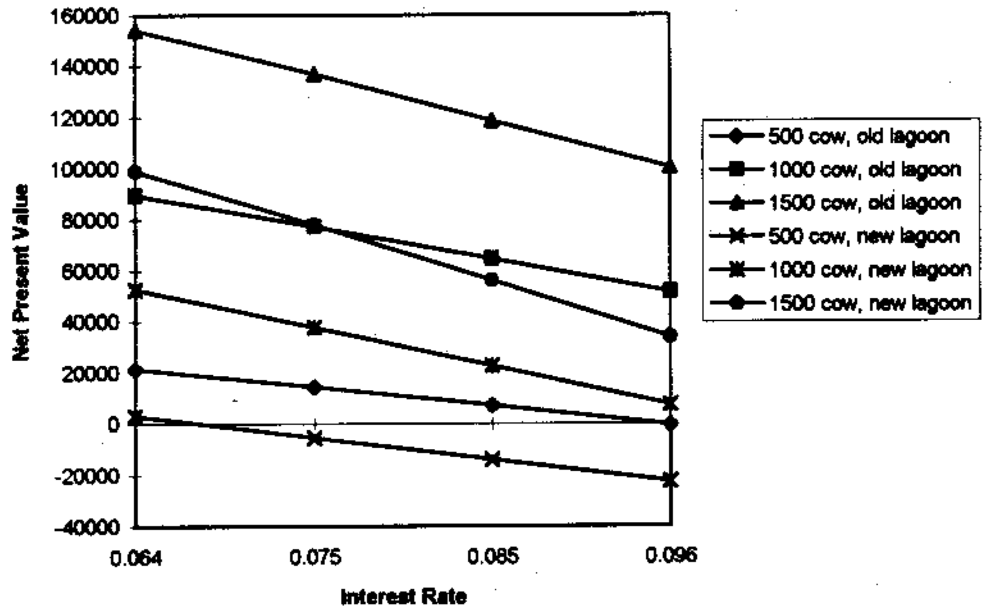


Figure 5. Freestall Flush Dairy, Covered Lagoon, Variation of Laggon Depth

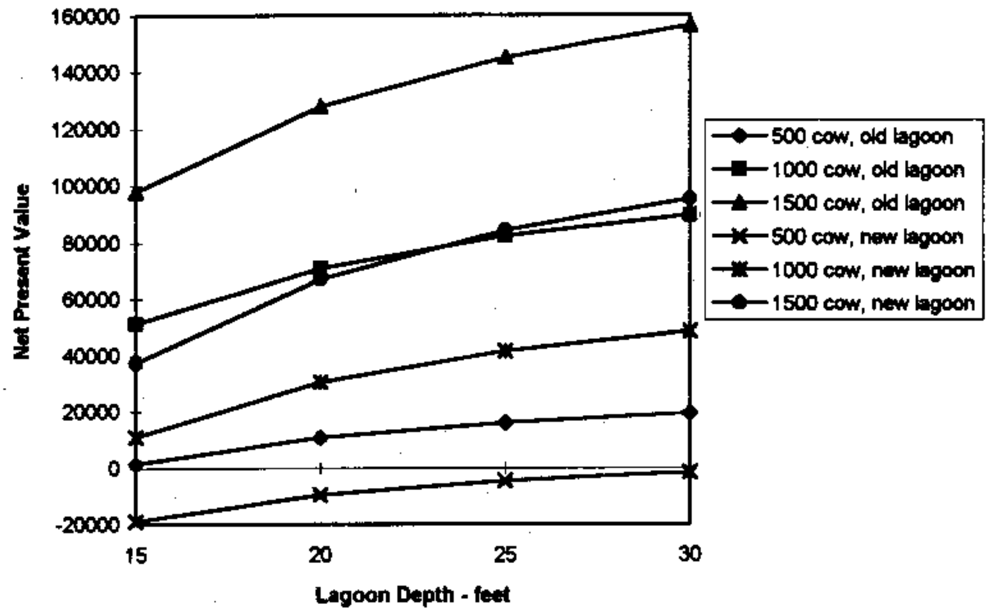


Figure 6. Freestall Flush Dairy, Covered Lagoon, Variation of Engine Up Time

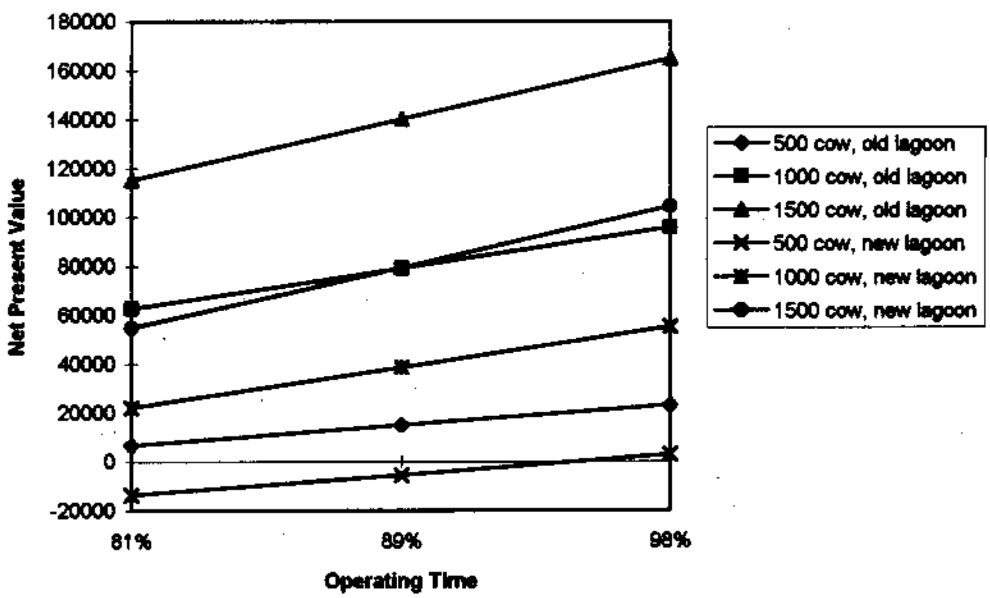


Figure 7. Freestall Flush Dairy, Covered Lagoon, Variation of Operation and Maintenance Cost

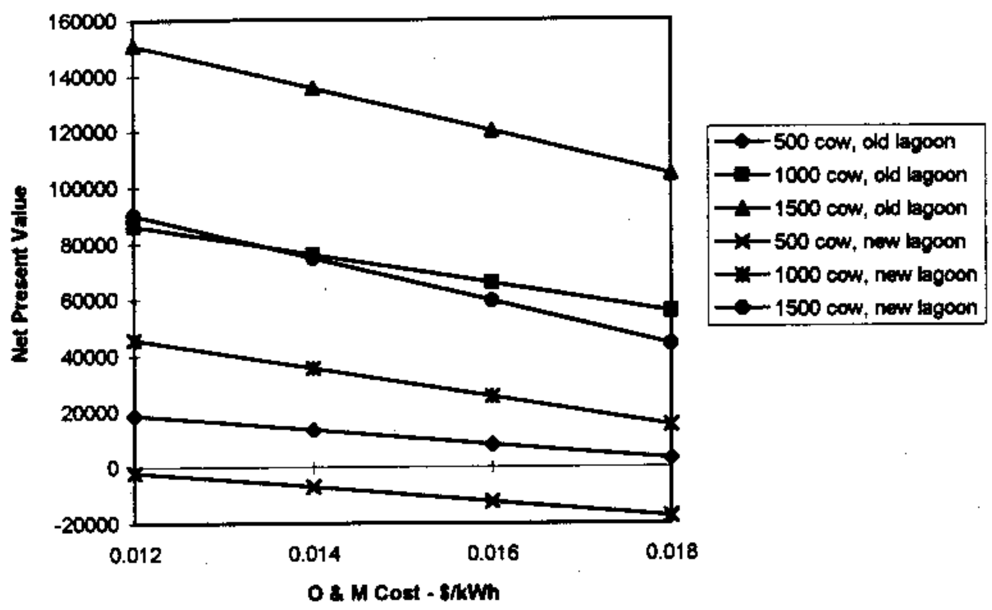


Figure 8. Freestall Flush Dairy, Covered Lagoon, Variation of Engine Efficiency

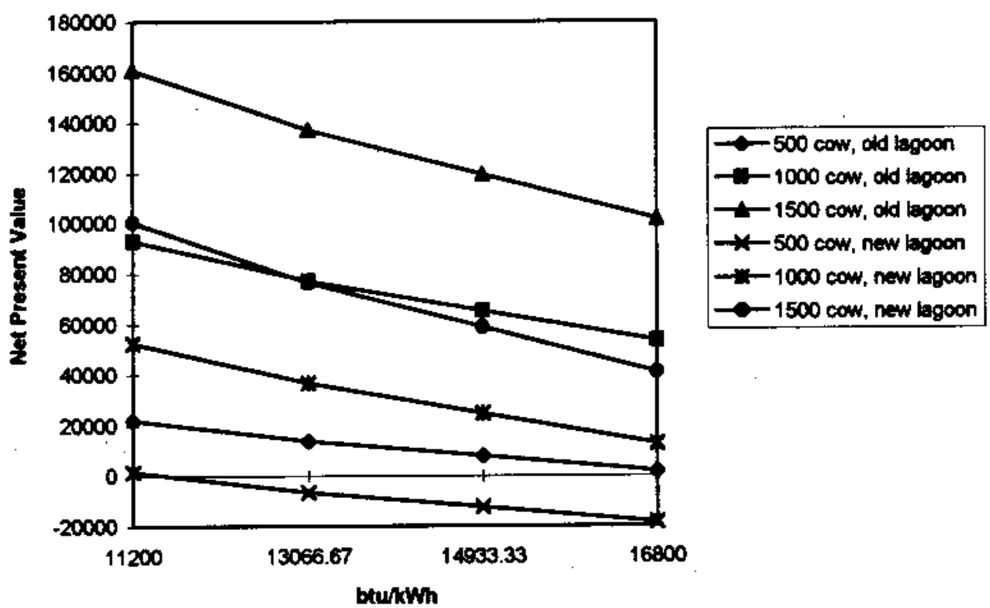


Figure 9. Freestall Flush Dairy, Covered Lagoon, Variation of Flush Volume

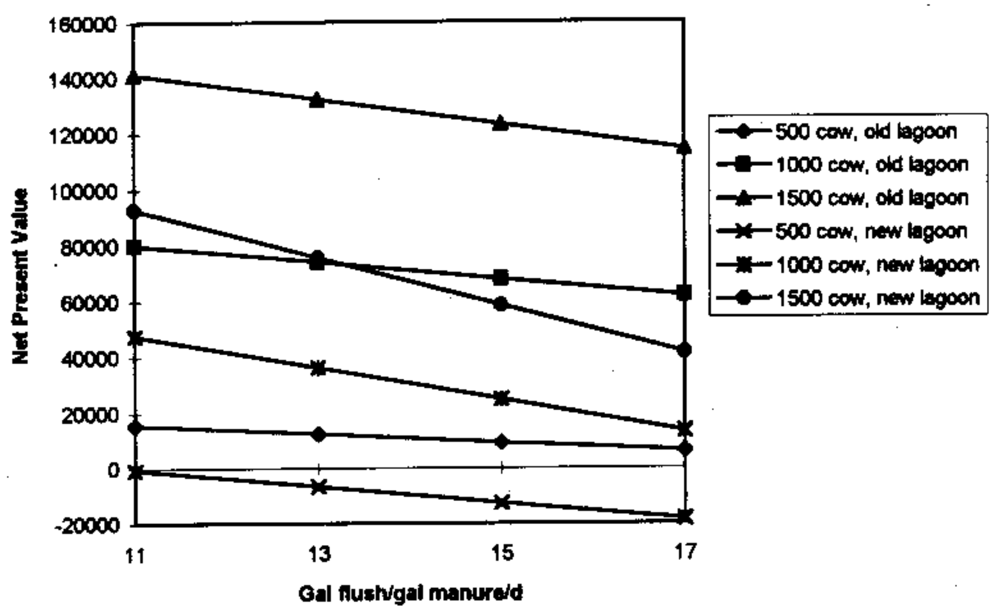


Figure 10. Freestall Flush Dairy, Covered Lagoon, Variation of Rat of Energy Inflation

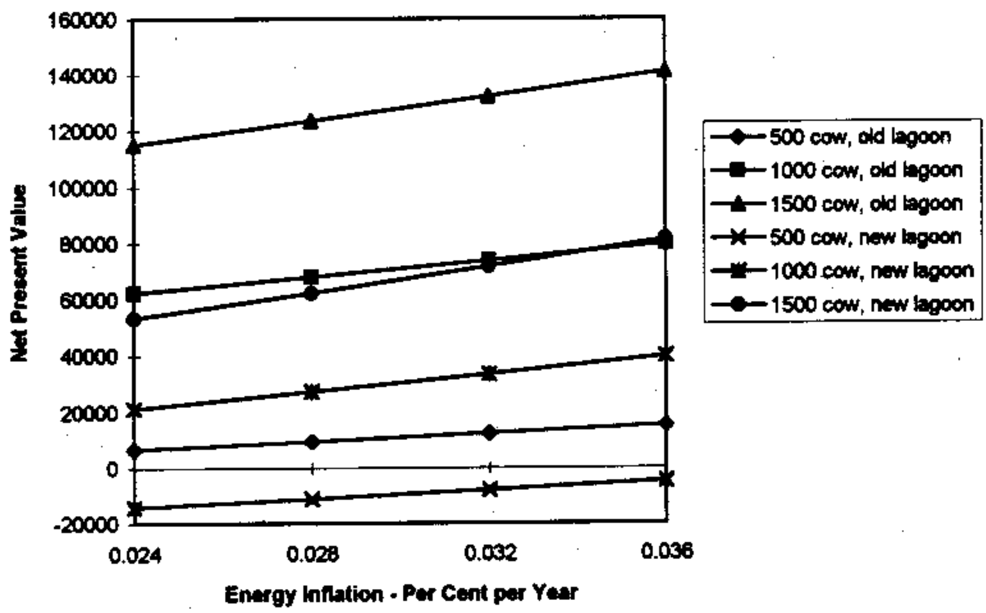


Figure 11. Freestall Flush Dairy, Covered Lagoon, Variation of Utility Buyback Rate

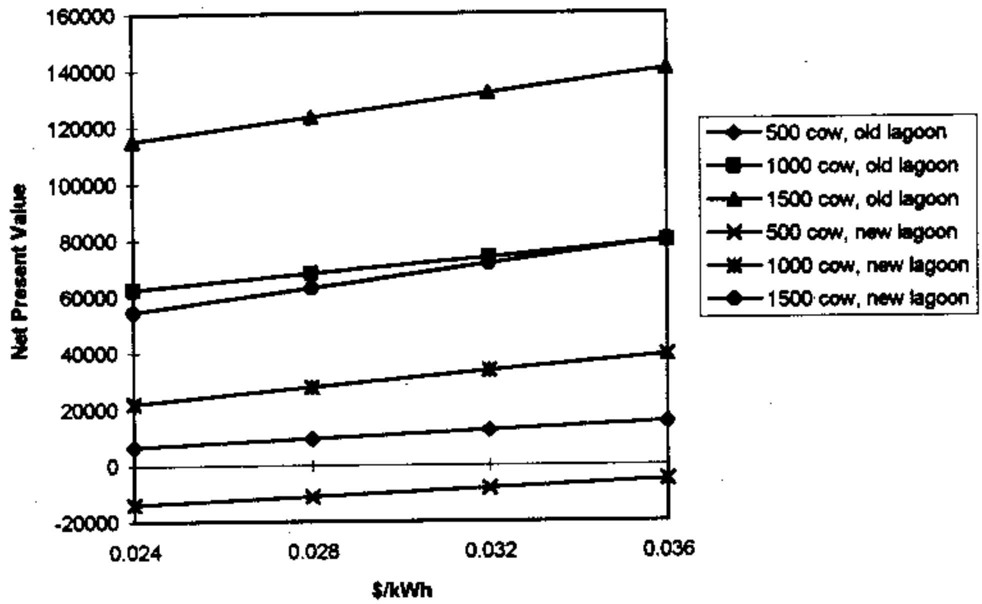


Figure 12. Freestall Flush Dairy, Covered Lagoon, Variation of Hot Water Value

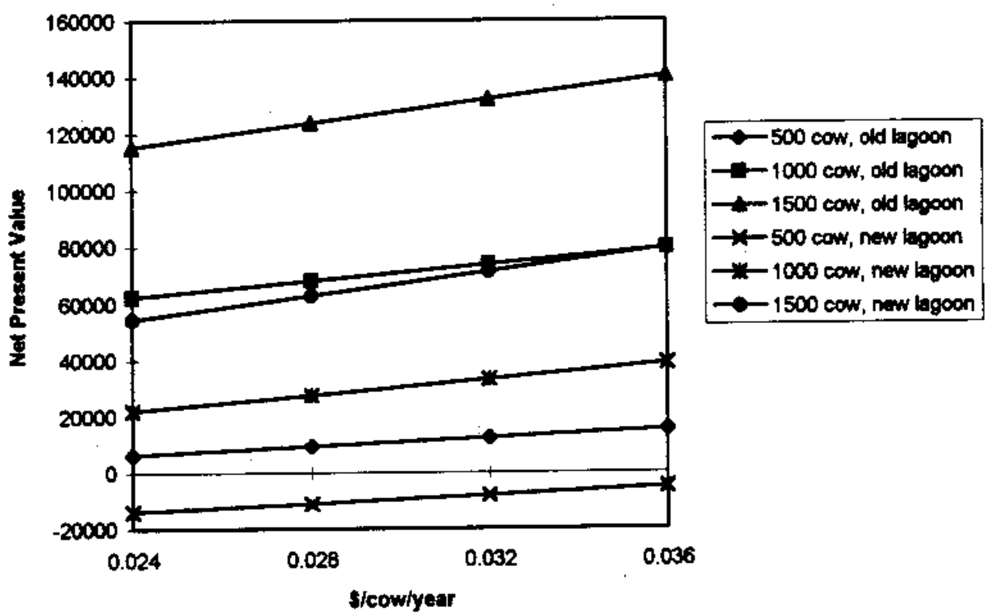


Figure 13. Freestall Flush Dairy, Covered Lagoon, Variation of Fresh Water Use

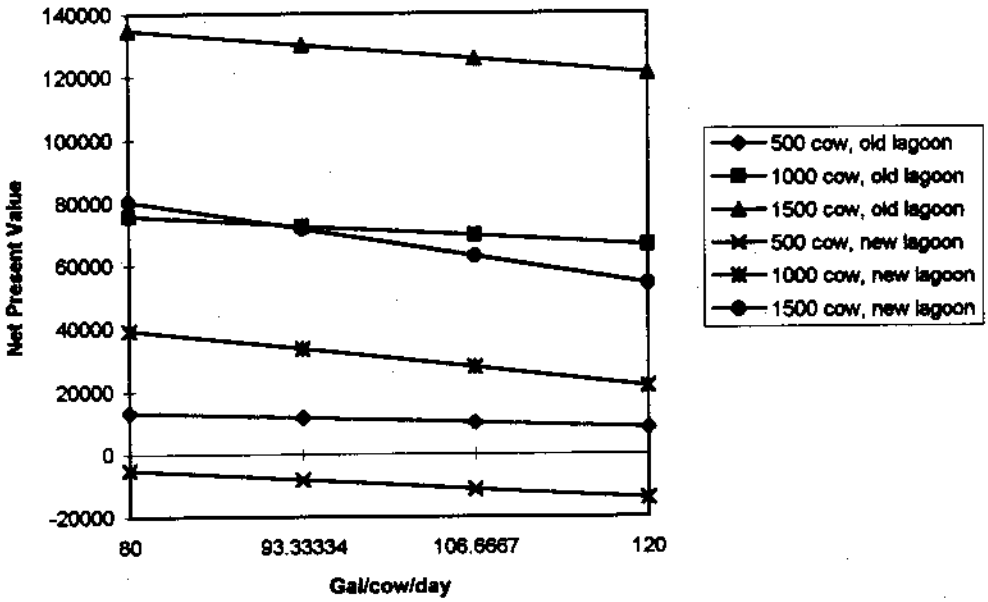


Figure 14. Feedlane Flush Dairy, Covered Lagoon, Variation of Value of Electricty

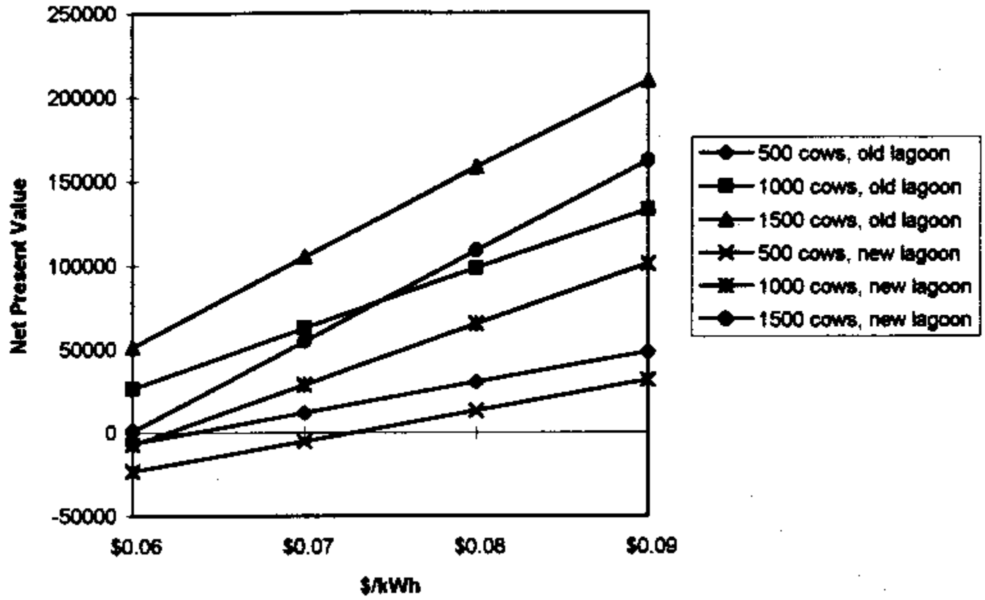


Figure 15. Feedlane Flush Dairy, Covered Lagoon, Variation of Engine Efficiency

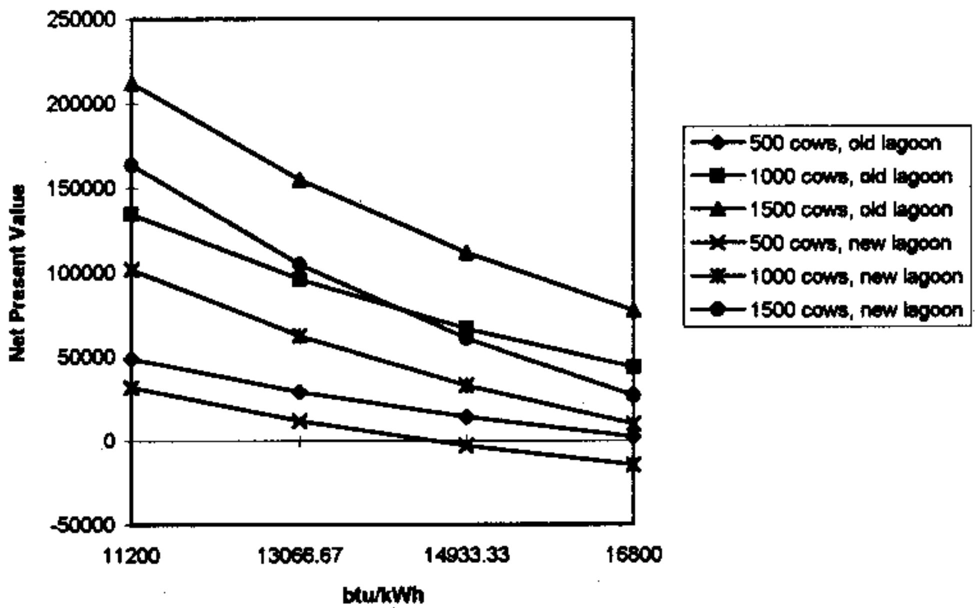


Figure 16. Feedlane Flush Dairy, Covered Lagoon, Variation of Engine Up Time

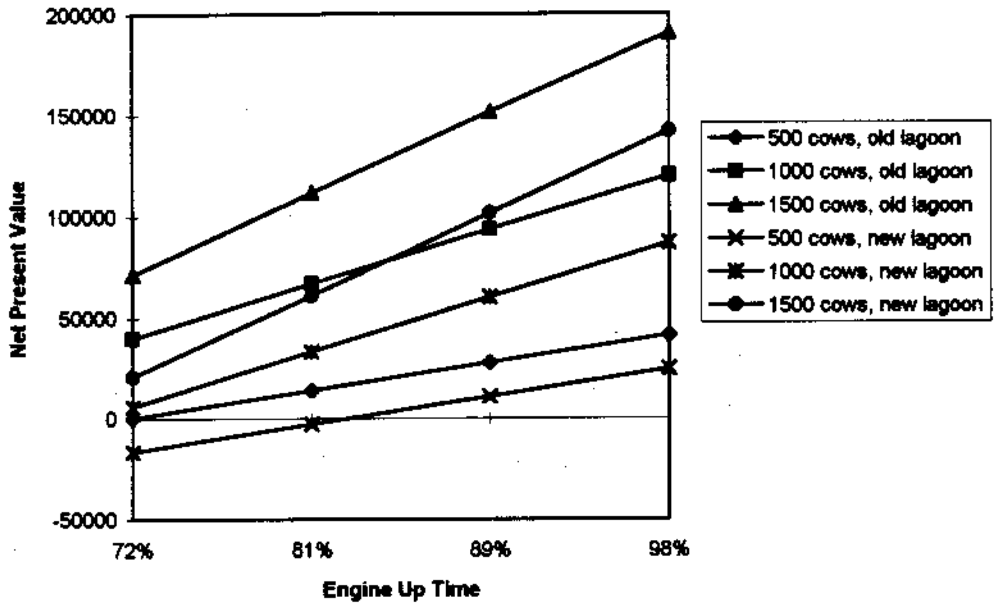


Figure 17. Feedlane Flush Dairy, Covered Lagoon, Variation of Capital Cost

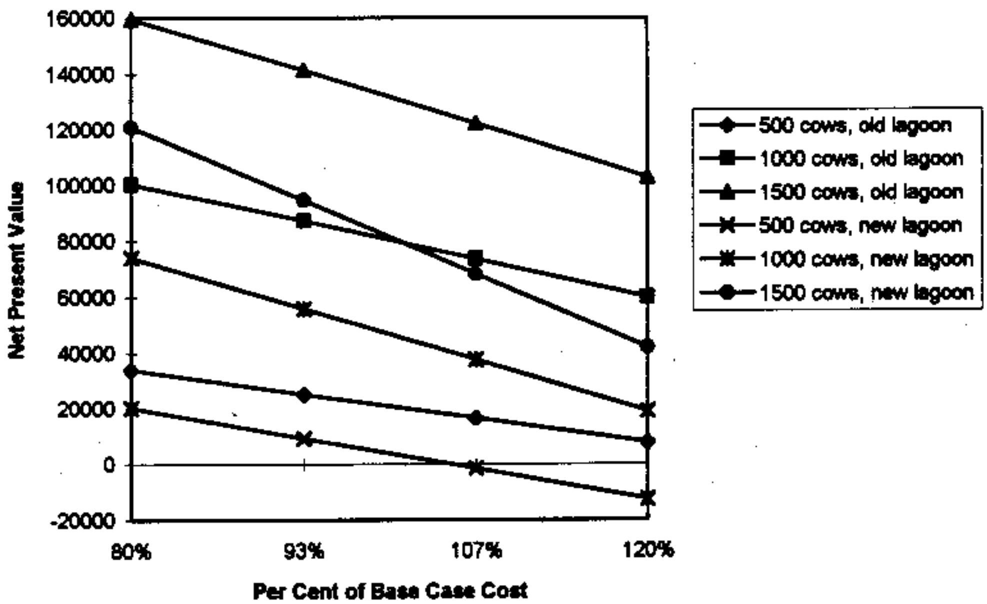


Figure 18. Feedlane Flush Dairy, Covered Lagoon, Variation of Discount Rate

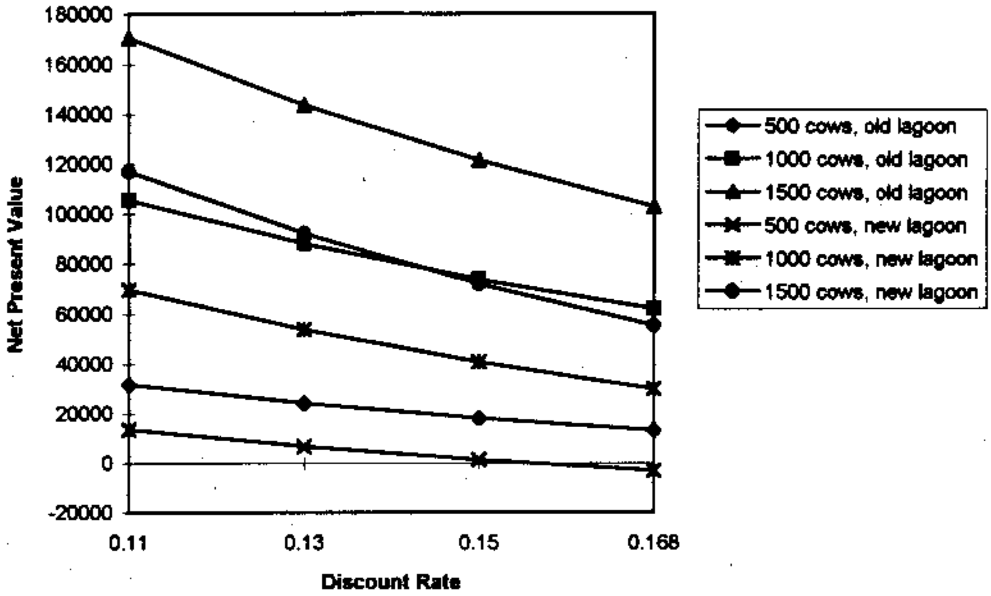


Figure 19. Feedlane Flush Dairy, Covered Lagoon, Variation of Interest Rate

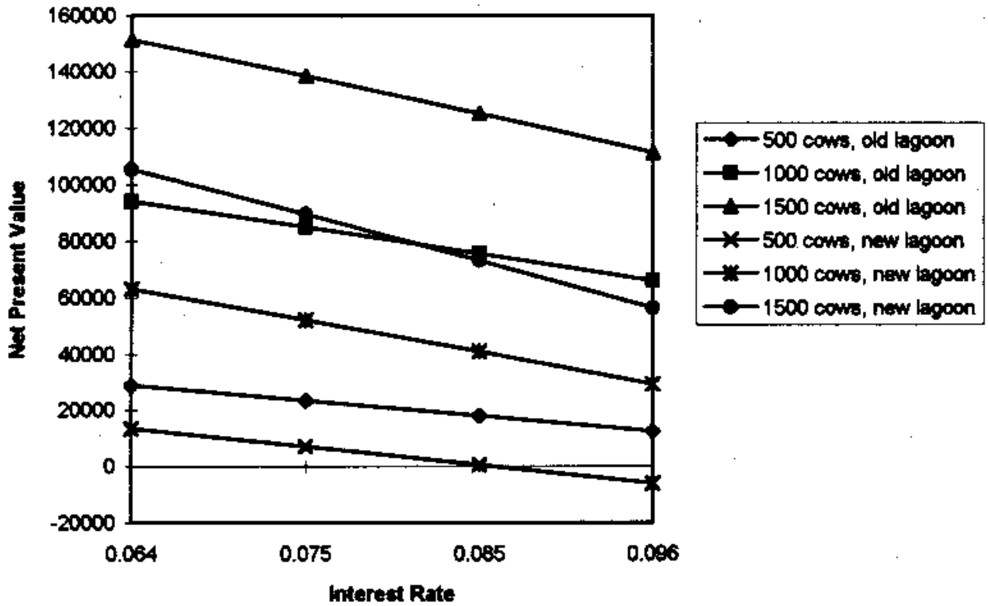


Figure 20. Feedlane Flush Dairy, Covered Lagoon, Variation of Lagoon Depth

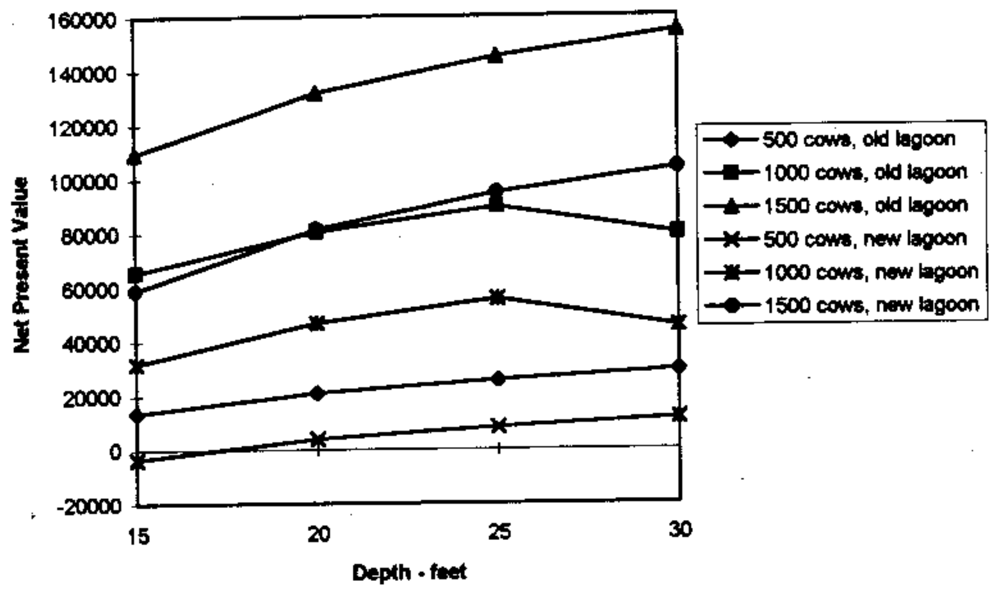


Figure 21. Feedlane Flush Dairy, Covered Lagoon, Variation of Operation and Maintenance Cost

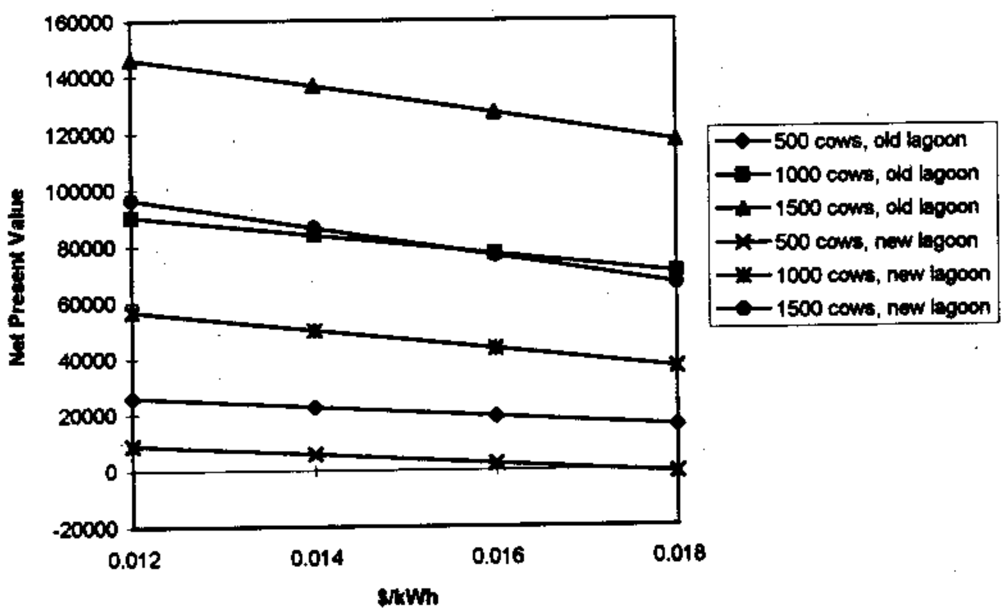


Figure 22. Feedlane Flush Dairy, Covered Lagoon, Variation of Flush Volume

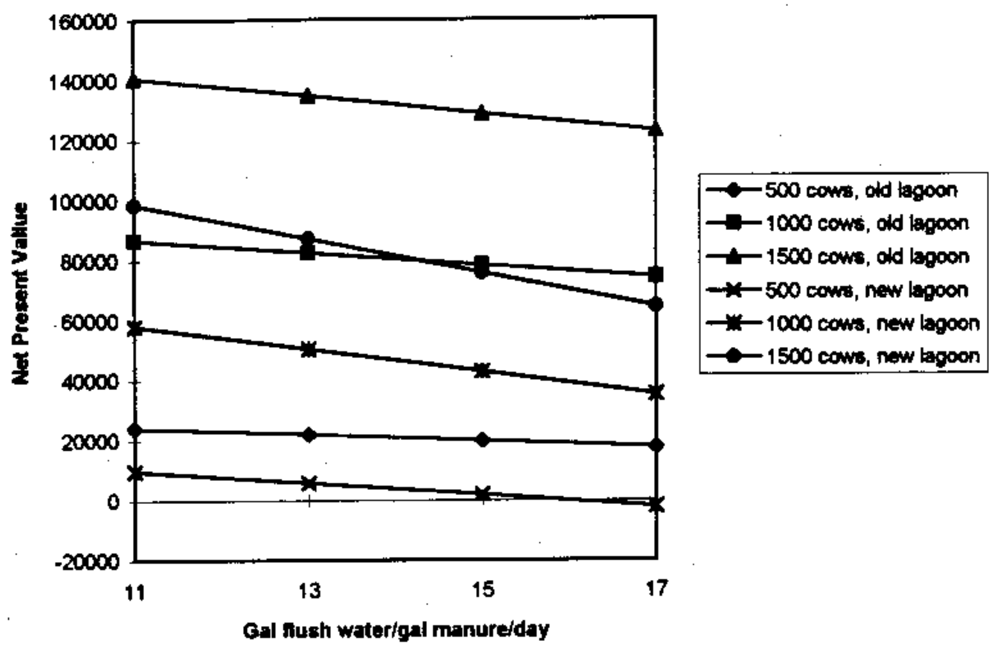


Figure 23. Feedlane Flush Dairy, Covered Lagoon, Variation Fresh Water Use

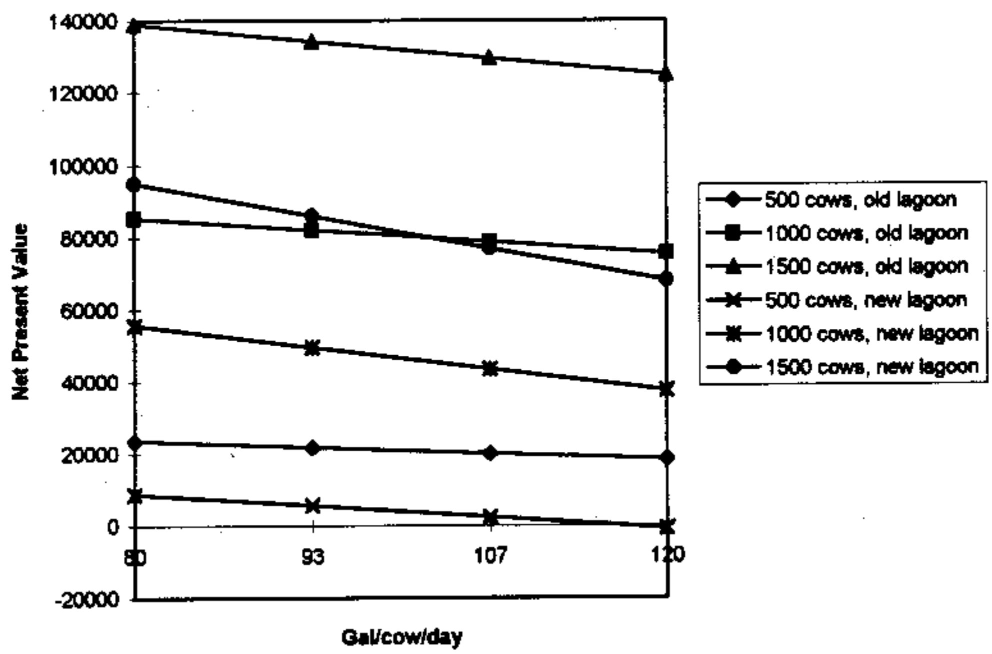


Figure 24. Feedlane Flush Dairy, Covered Lagoon, Variation of Energy Inflation Rate

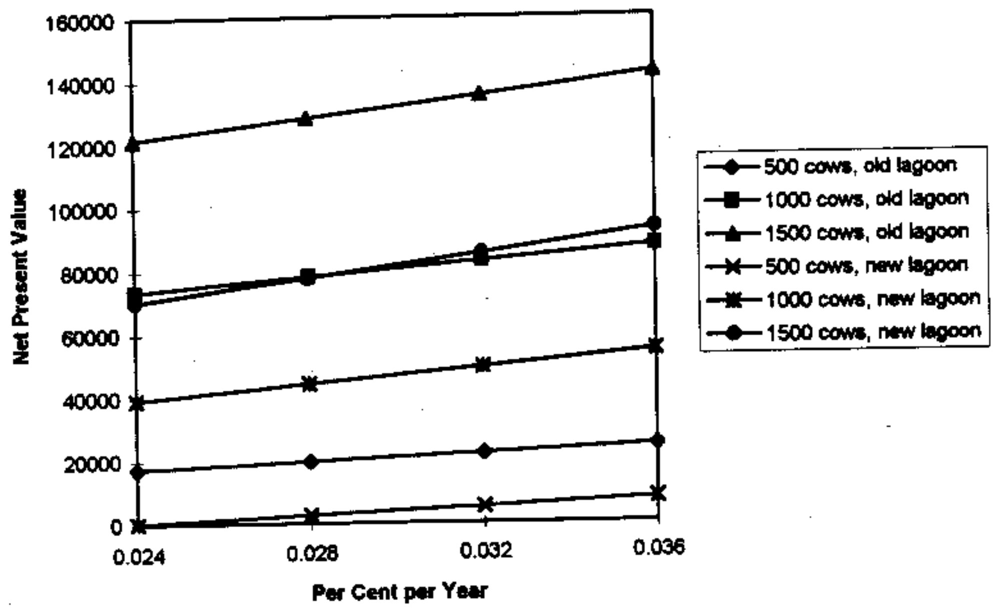


Figure 25. Feedlane Flush Dairy, Covered Lagoon, Variation of Hot Water Value

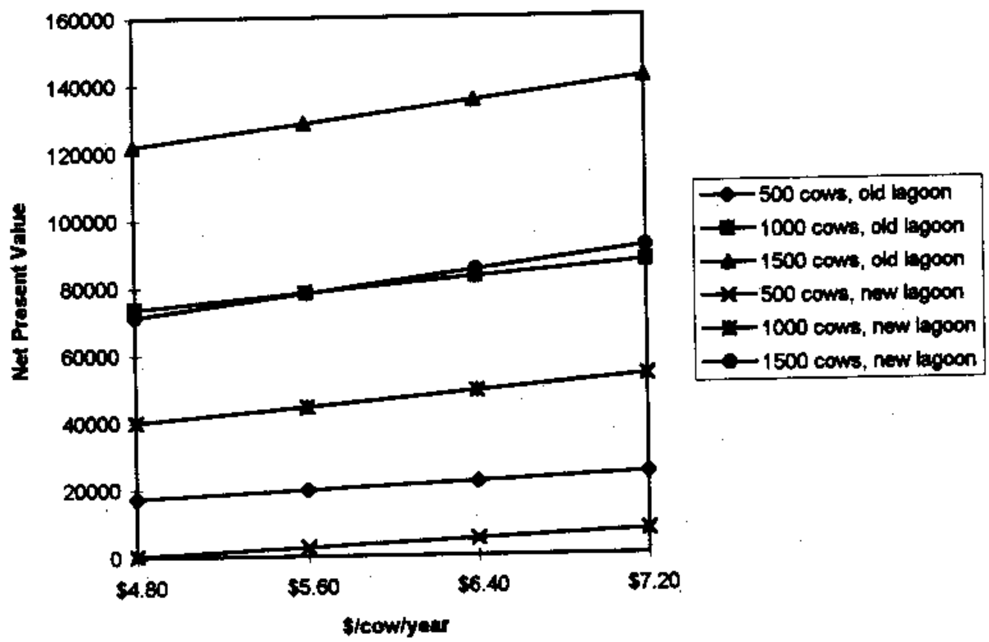


Figure 26 . Plug Flow, Base Case Comparisons

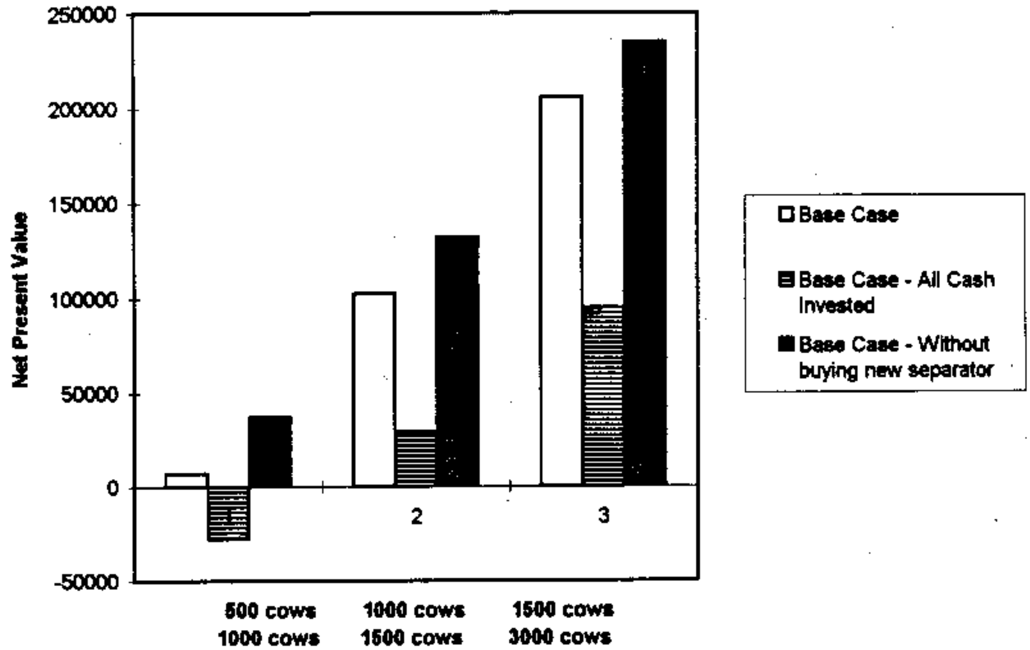
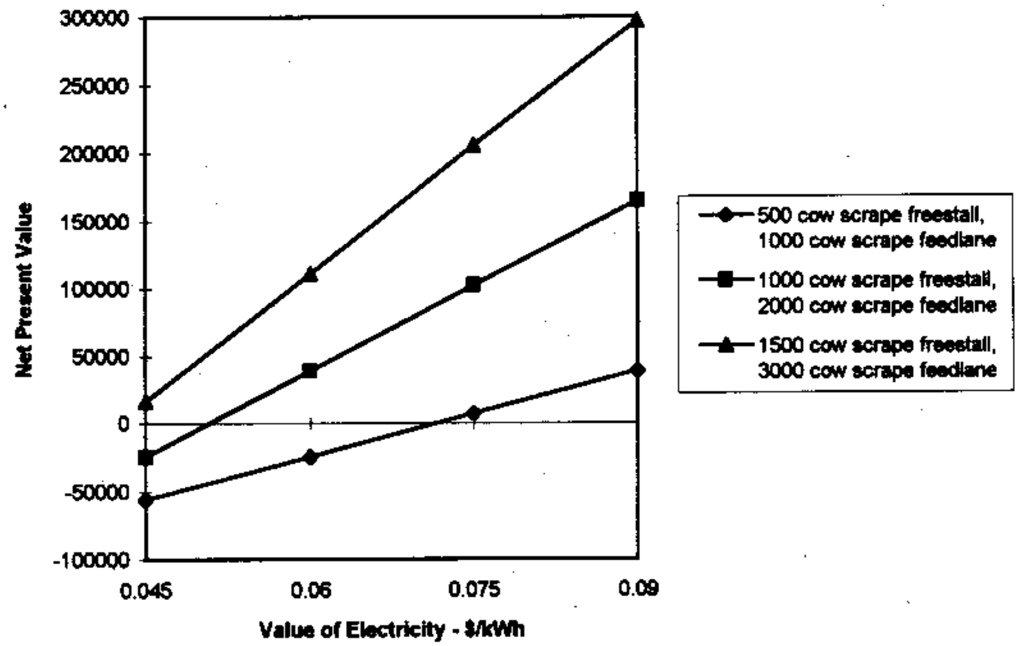


Figure 27. Plug Flow, Electricity Value Variation



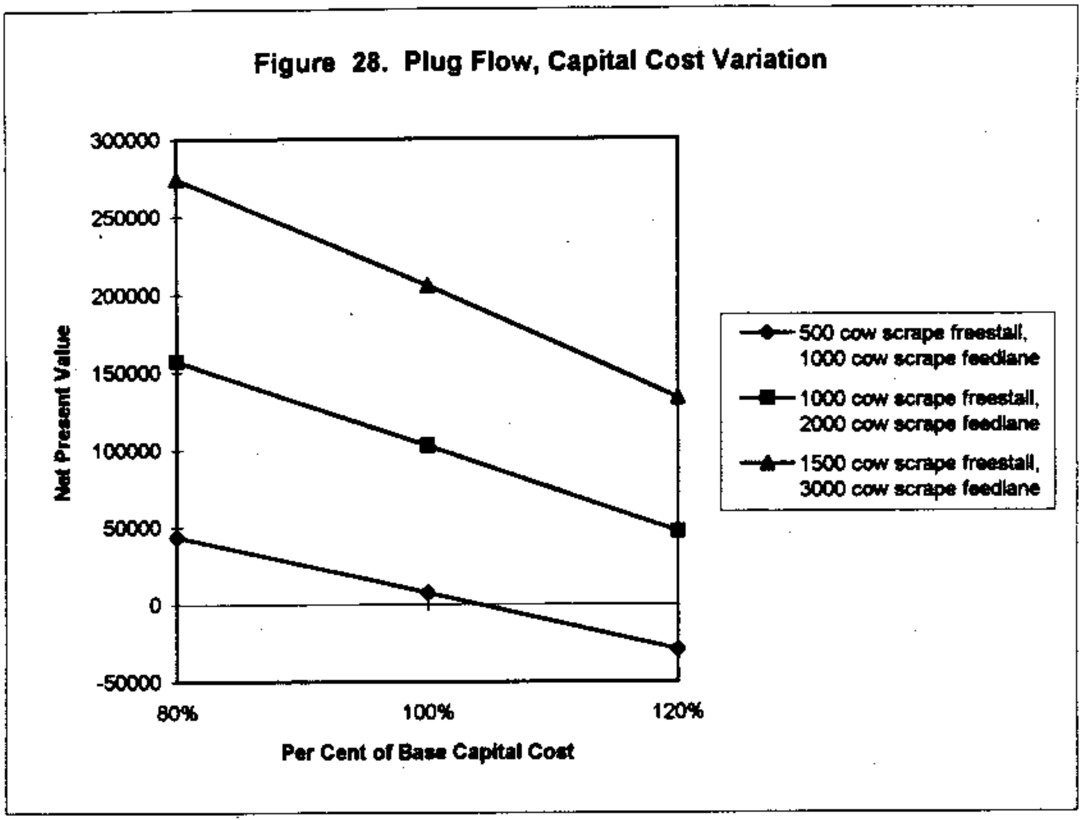


Figure 28. Plug Flow, Capital Cost Variation
300000
250000
200000
150000
100000
50000
0
-50000
Net Present Value
80%
100%
120%
Per Cent of Base Capital Cost
500 cow scrape freestall, 1000 cow scrape feedlane
1000 cow scrape freestall, 2000 cow scrape feedlane
1500 cow scrape freestall, 3000 cow scrape feedlane

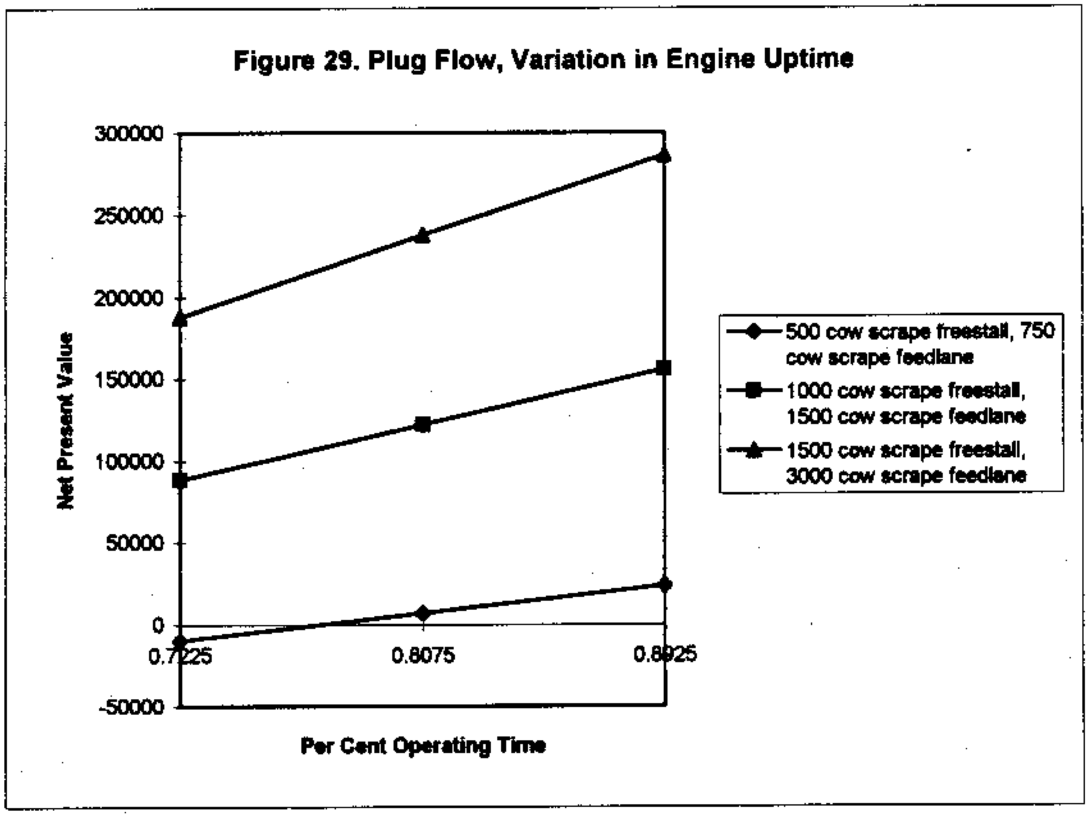


Figure 29. Plug Flow, Variation in Engine Uptime
300000
250000
200000
150000
100000
50000
0
-50000
Net Present Value
0.7225
0.8075
0.8925
Per Cent Operating Time
500 cow scrape freestall, 750 cow scrape feedlane
1000 cow scrape freestall, 1500 cow scrape feedlane
1500 cow scrape freestall, 3000 cow scrape feedlane

Figure 30. Plug Flow, Variation of Engine Efficiency

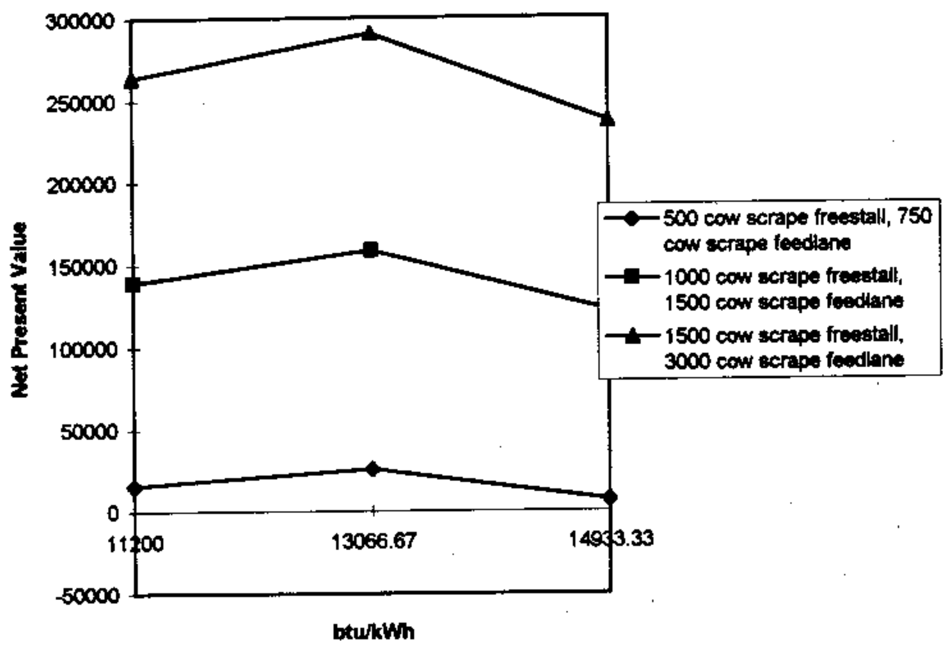


Figure 31. Plug Flow, Discount Rate Variation

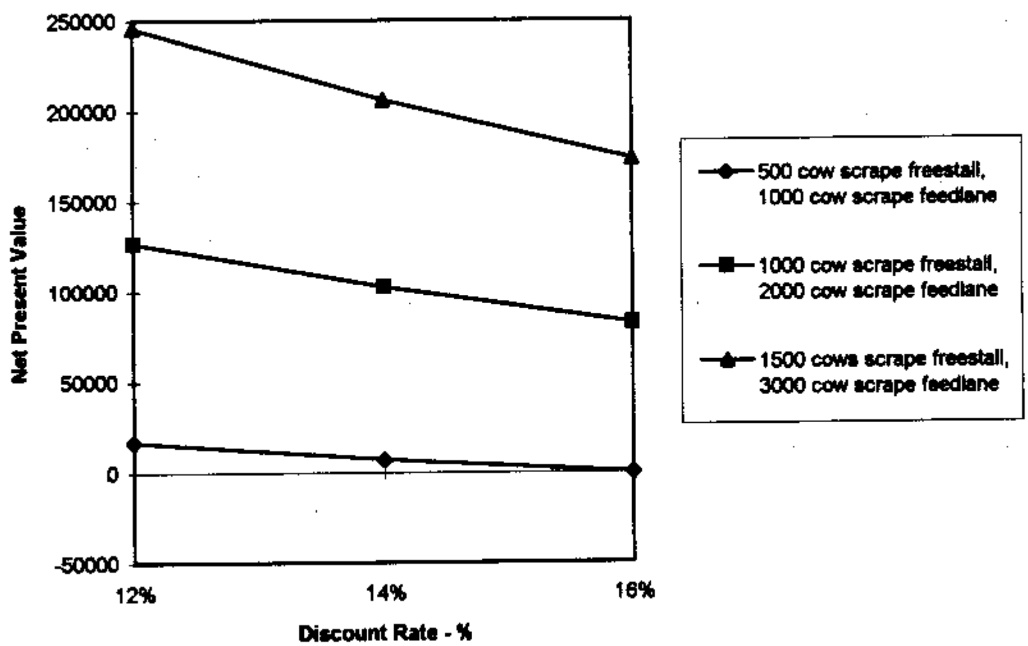


Figure 32. Plug Flow, Interest Rate Variation

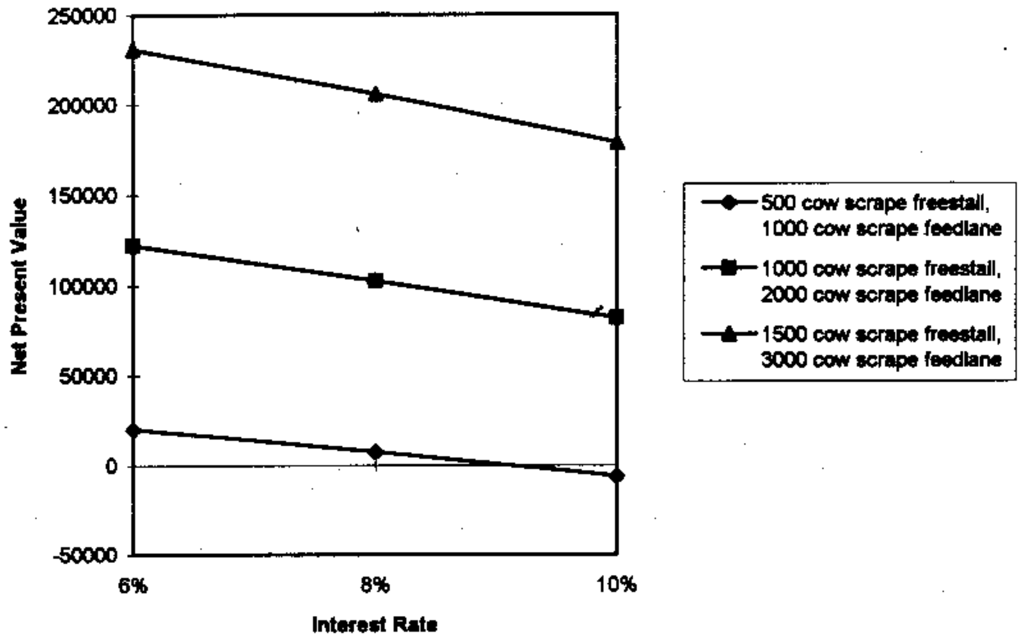


Figure 33. Plug Flow, Variation of Digested Solids Sale Value

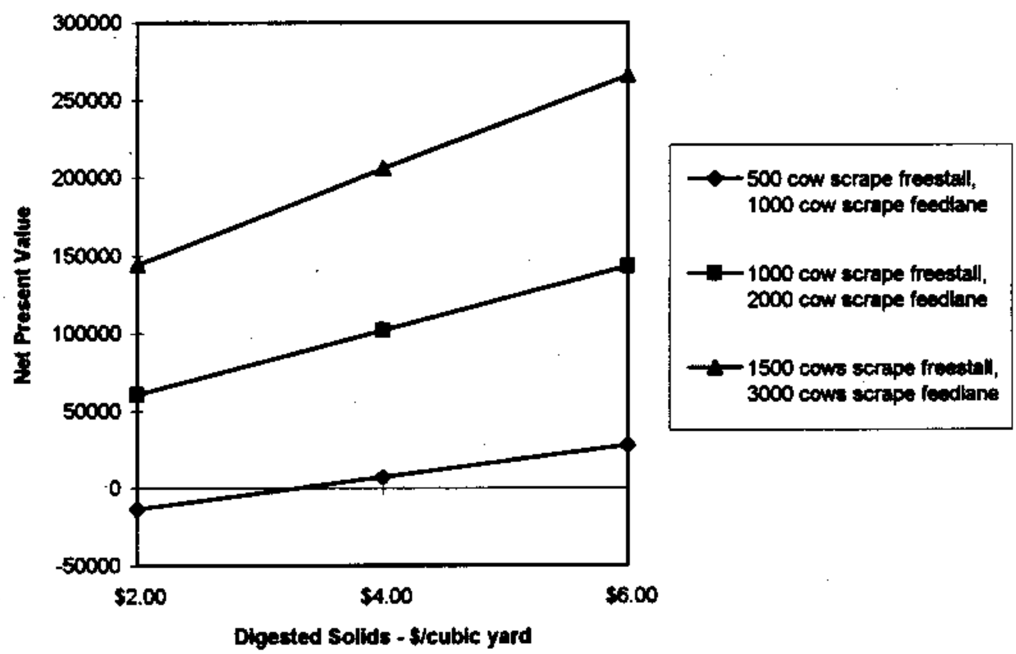


Figure 34. Plug Flow, Variation of Engine Operation and Maintenance Costs

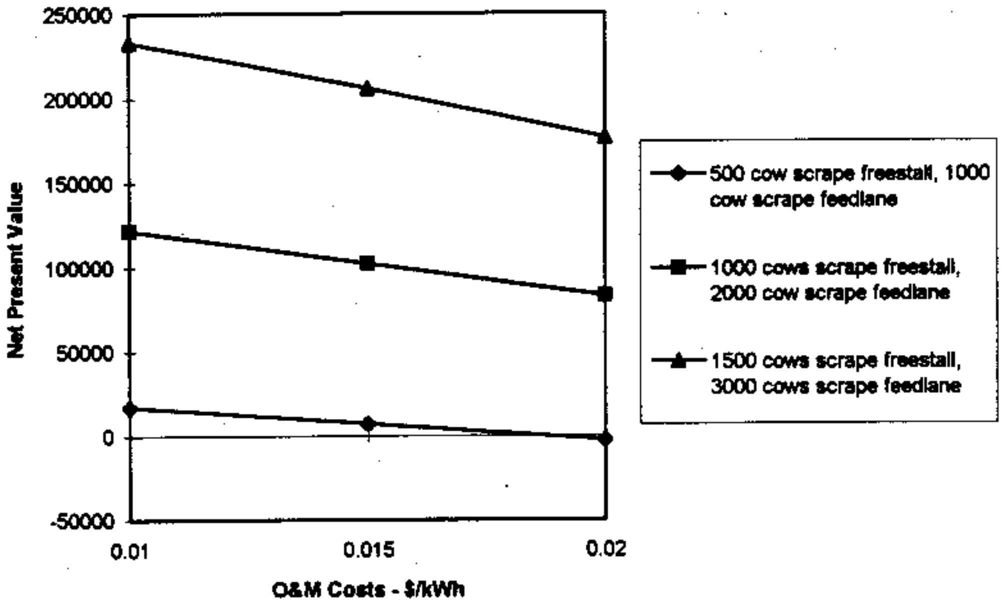
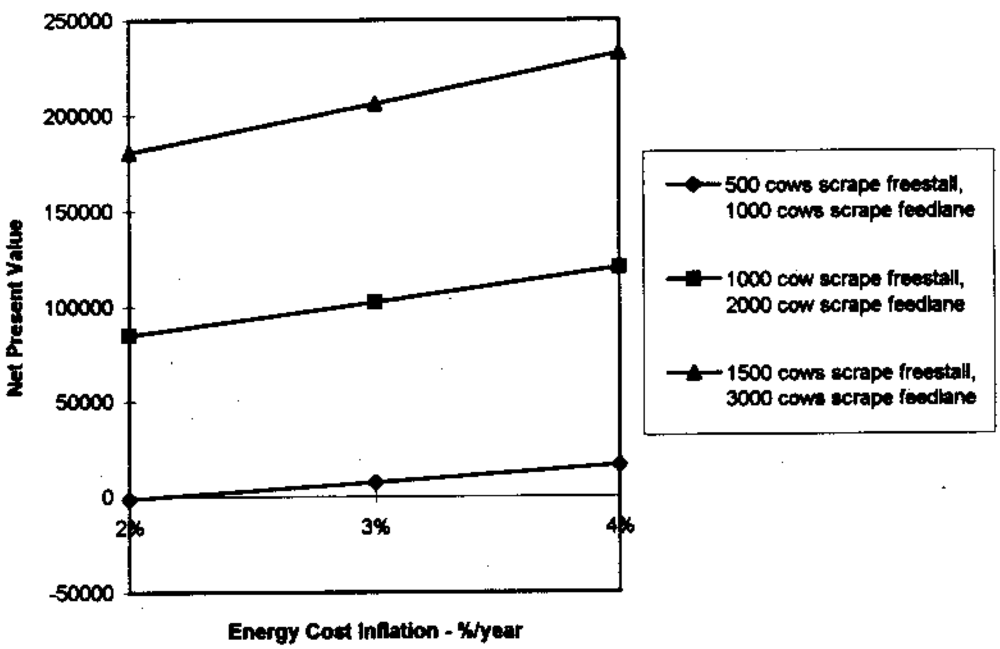


Figure 35. Plug Flow, Variation of Energy Inflation



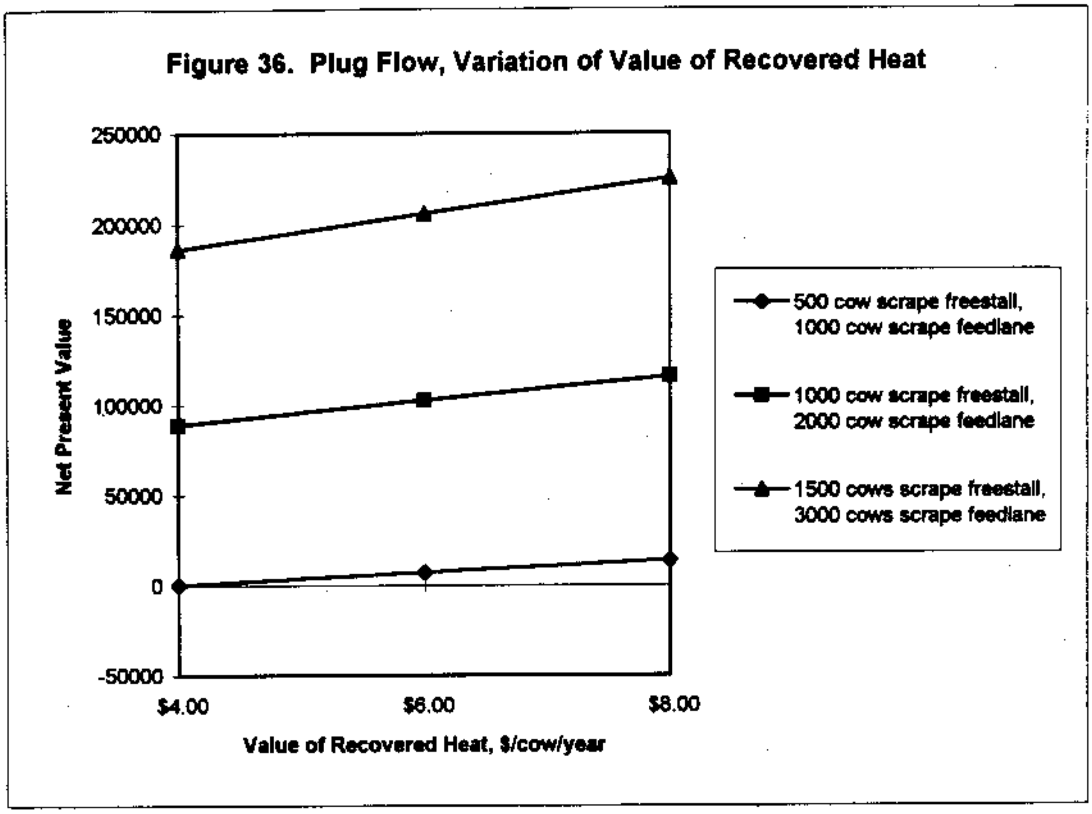


Figure 36. Plug Flow, Variation of Value of Recovered Heat
250000
200000
150000
100000
50000
0
-50000
Net Present Value
$4.00
$6.00
$8.00
Value of Recovered Heat, $/cow/year
500 cow scrape freestall, 1000 cow scrape feedlane
1000 cow scrape freestall, 2000 cow scrape feedlane
1500 cows scrape freestall, 3000 cows scrape feedlane

Appendix I Data Collected at Sharp Ranch Covered Lagoon

Data source: Sharp Ranch's site monitoring results in Figures 1, 1A, 2 and 2A.

Table 1. Temperature (F) Monitoring Record

	Lagoon #		Lagoon1	Lagoon1	Lagoon1	Lagoon1	Lagoon3	Lagoon3
	Depth		3 in	3 ft	3 in	3 ft	3 in	3 ft
	Location		Entry	Entry	Exit	Exit	Exit	Exit
Month	Date & Time	Ambient Temp.	Lagoon Temperature					
Sep-94	9/1/94 7:00	69.5	70.8		72.5		66	73
Oct-94								
Nov-94								
Dec-94	11/30/94 7:45	38	47.5	54	49	55		
Jan-95								
Feb-95								
Mar-95	2/28/95 9:45	56	63	59	58	58	57.5	57
Apr-95	3/31/95 9:30	65	61	59	58.5	59	64	59.2
May-95	5/1/95 15:20	62	70.5	65	64	65	76	64
Jun-95	6/2/95 7:00	66	69.5	70.5	66	70	65	
Jul-95	7/8/95 7:25	77.5	76	76.75	74	74.5	76.25	78
Aug-95	8/2/95 11:45	85	80.5	76	78.5	76	91	79
Sep-95	9/5/95 6:50	63	71	74	72.5	75	69.5	73

Table 2. BOD, COD, TSS and TVS Monitoring Results *

	BOD (mg/l)		COD (mg/l)		TSS (mg/l)		TVS (mg/l)	
Month	Lagoon1	Lagoon3	Lagoon1	Lagoon3	Lagoon1	Lagoon3	Lagoon1	Lagoon3
Sep-94	4900	2790	6464	996	4173	517	4800	960
Oct-94	840		1600		1838		1200	
Nov-94	2640		4850		396		890	
Dec-94	1440	1530	1060	1120	2045	1965	1096	1332
Jan-95	2400		2563		1360		1728	
Feb-95	2640		2550		507		1350	
Mar-95	3300	3450	1380	1279	308	203	1450	1580
Apr-95	1440	1650	1230	1220	736	500	1164	1223
May-95	2580	3660	1190	1250	750	767	1482	1258
Jun-95	3240	3060	1960	1750	558	420	1655	1548
Jul-95	3480	3180	2010	1720	481	318	1923	2031
Aug-95	3360	3720	2200	2990	422	2927	1506	3220
Sep-95	3420	2940	2640	2020	542	356	1232	1257

* BOD: Biological Oxygen Demand; COD: Chemical Oxygen Demand; TSS: Total Suspended Solids; TVS: Total Volatile Solids.

Table 3. pH and Nitrogen Monitoring Results *

Month	PH		TKN (mg/l)		NH4-N (mg/l)	
	Lagoon1	Lagoon3	Lagoon1	Lagoon3	Lagoon1	Lagoon3
Sep-94	7.6	8	350	260	58.2	54.3
Oct-94	7.7		800		743	
Nov-94	7.3		1400		695.7	
Dec-94	7.1	7.7	1000	700	547	497
Jan-95	7.6		1800		533	
Feb-95	7.1				739	
Mar-95	8.3	8.5			737	691
Apr-95	7.8	8.1	1200	500	841	252
May-95					794	543
Jun-95	7.4	7.5			844	727
Jul-95	7.3	7.7			688	612
Aug-95	7.2	7.8			724	565
Sep-95	7.2	8.1			758	539

* TKN: Total Kjeldahl Nitrogen (Total Organic Nitrogen); NH4-N: Ammonium Nitrogen.

Table 4. Gas Monitoring Results and Lab Information

Month	CO2 (vol.%)	O2 (vol.%)	N2 (vol.%)	CH4 (vol.%)	H2S (ppm)	Gross BTU/cuft	Zalco#	Mid State#
Sep-94	24.13	3.527	14.171	58.174	50	589.87	41108	30866
Oct-94	28.735	0.091	0.409	70.281	2400	725.38	41371	31650
Nov-94	24.12	1.13	3.81	70.85	2000	719.17	41781	31959
Dec-94	18.503	5.682	22.818	52.998	19	537.21	42092	32291
Jan-95	21.523	0.213	1.599	76.137	1200	783.7	42377	32636
Feb-95	25.53	2.54	10.14	61.17	700	639.35	42710	32891
Mar-95	22.48	4.364	16.596	56.074	330	584.46	43065	33205
Apr-95	16.816	9.582	36.487	36.659	78	382.95	43381	33628
May-95	28.87	0.43	2.36	68.06	1500	692.43	43762	34080
Jun-95	29.34	0.36	1.35	68.79	3400	698.83	44158	34707
Jul-95	24.83	0.707	3.85	70.42	1600	715.57	44604	35336
Aug-95								36046
Sep-95	24.59	2.02	6.4	66.85	1500	678.93	45241	36603

Table 5. Adjusted Biogas Composition *

	Original				CO2/CH4	Adjusted	
Month	CO2 (vol.%)	O2 (vol.%)	N2 (vol.%)	CH4 (vol.%)	(mole ratio)	CO2 (vol.%)	CH4 (vol.%)
Sep-94	24.13	3.527	14.171	58.174	0.41	29.32	70.68
Oct-94	28.735	0.091	0.409	70.281	0.41	29.02	70.98
Nov-94	24.12	1.13	3.81	70.85	0.34	25.40	74.60
Dec-94	18.503	5.682	22.818	52.998	0.35	25.88	74.12
Jan-95	21.523	0.213	1.599	76.137	0.28	22.04	77.96
Feb-95	25.53	2.54	10.14	61.17	0.42	29.45	70.55
Mar-95	22.48	4.364	16.596	56.074	0.40	28.62	71.38
Apr-95	16.816	9.582	36.487	36.659	0.46	31.45	68.55
May-95	28.87	0.43	2.36	68.06	0.42	29.78	70.22
Jun-95	29.34	0.36	1.35	68.79	0.43	29.90	70.10
Jul-95	24.83	0.707	3.85	70.42	0.35	26.07	73.93
Aug-95							
Sep-95	24.59	2.02	6.4	66.85	0.37	26.89	73.11

* Assume air leak occurred during sampling.

Figure 1. Biological Oxygen Demand (BOD) Monitoring Results

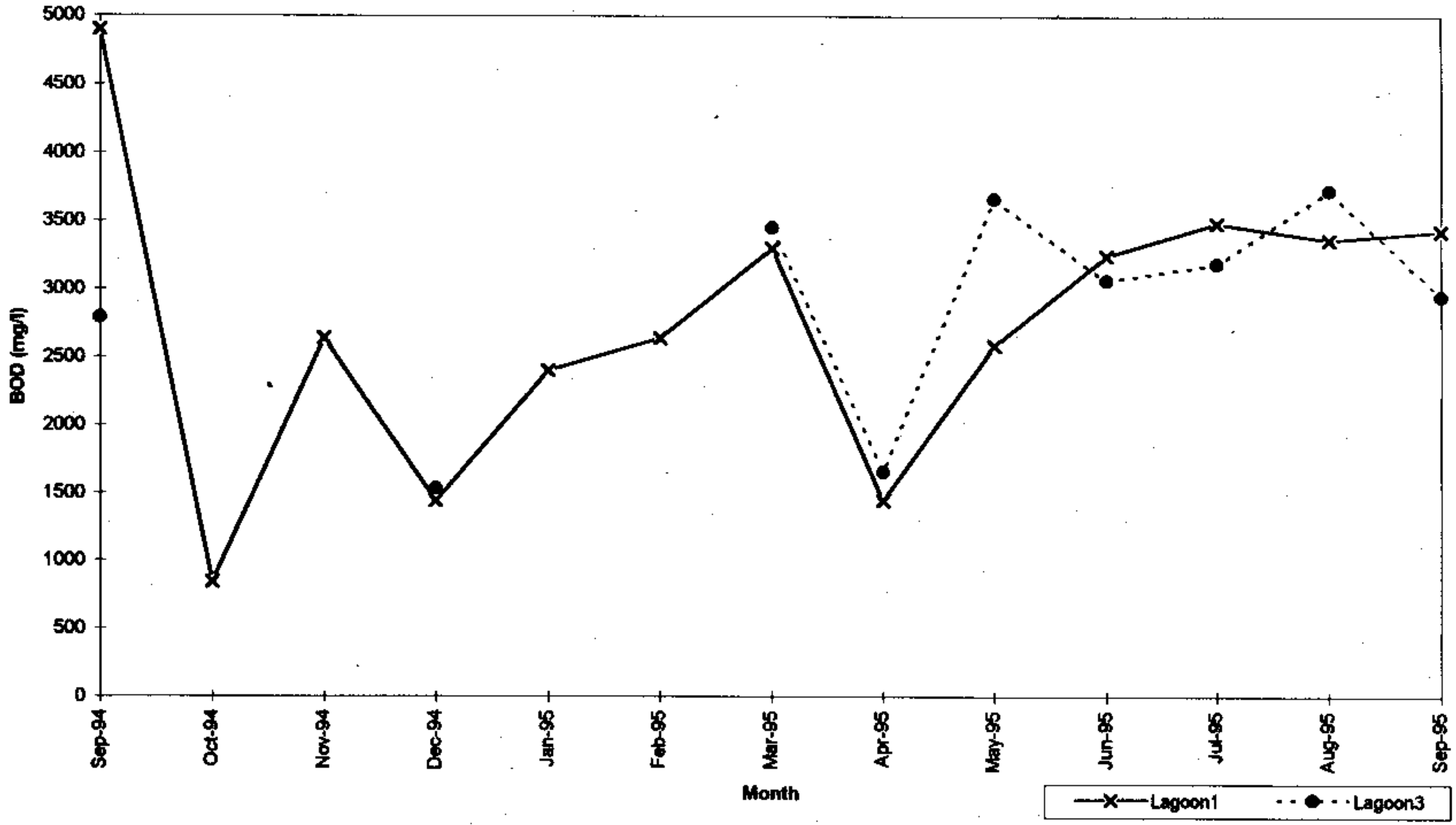


Figure 2. Adjusted Biogas Composition
After Discounting Air Leaked into the Samples

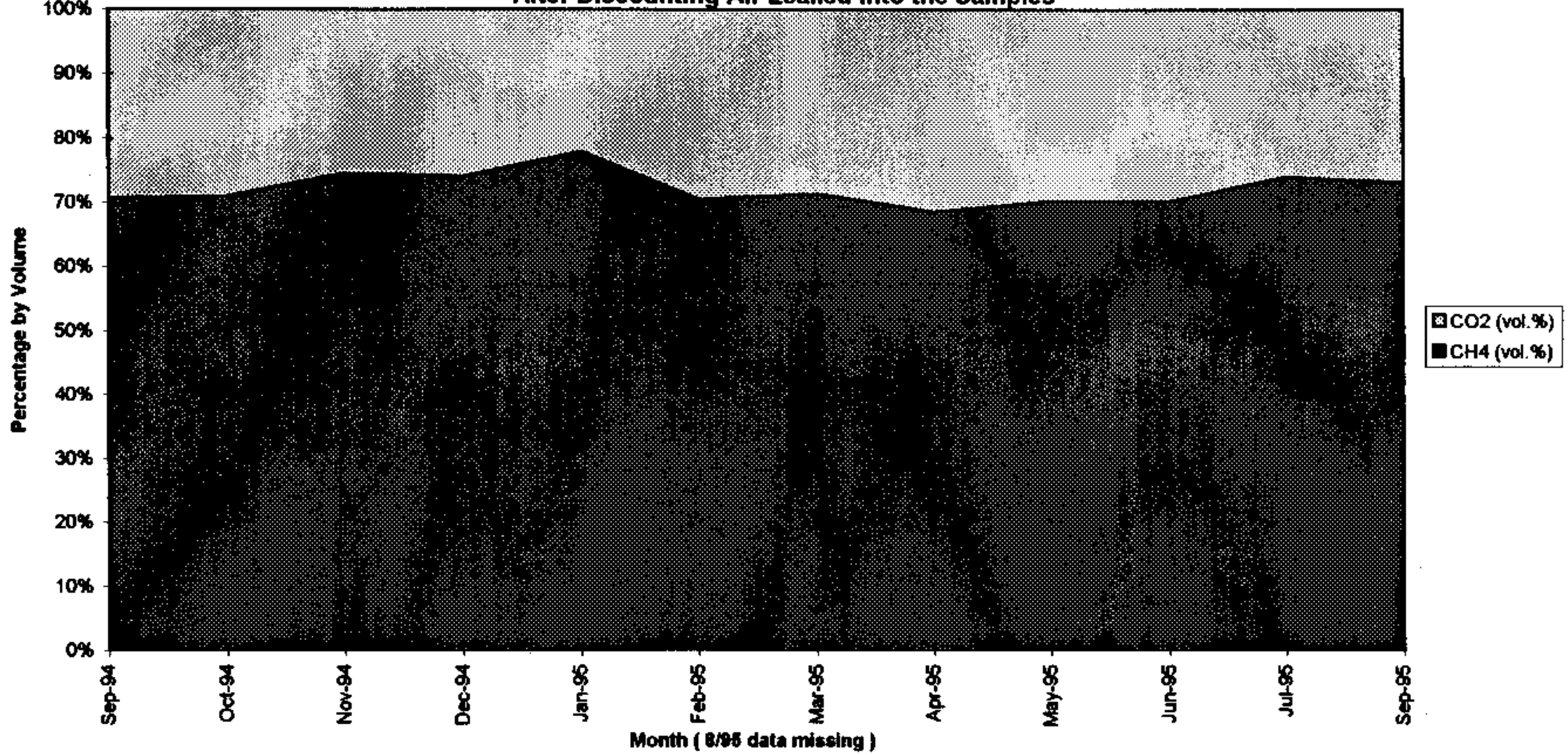


Figure 5. Temperature Comparison of Lagoons #1 and #3

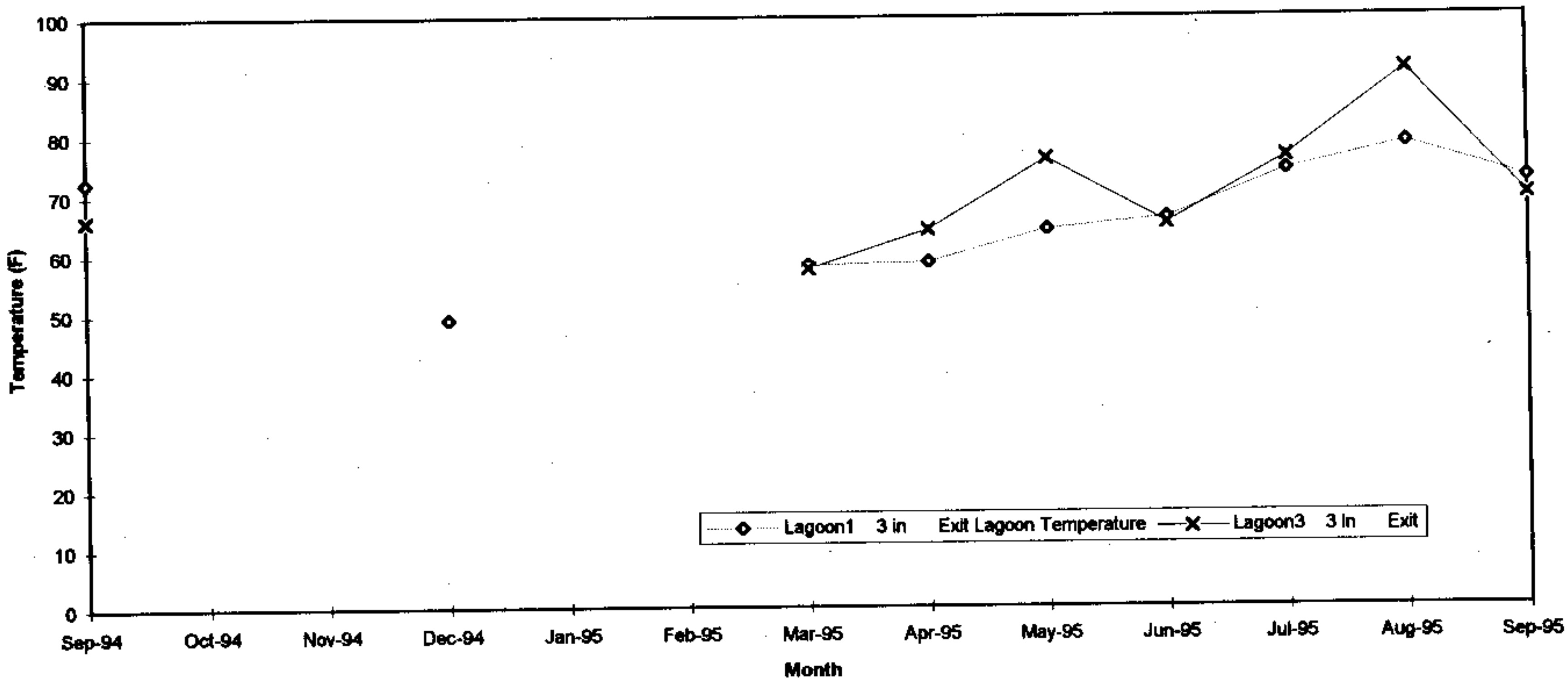


Figure 7. Total Organic Nitrogen Measured in Lagoons #1 and #3

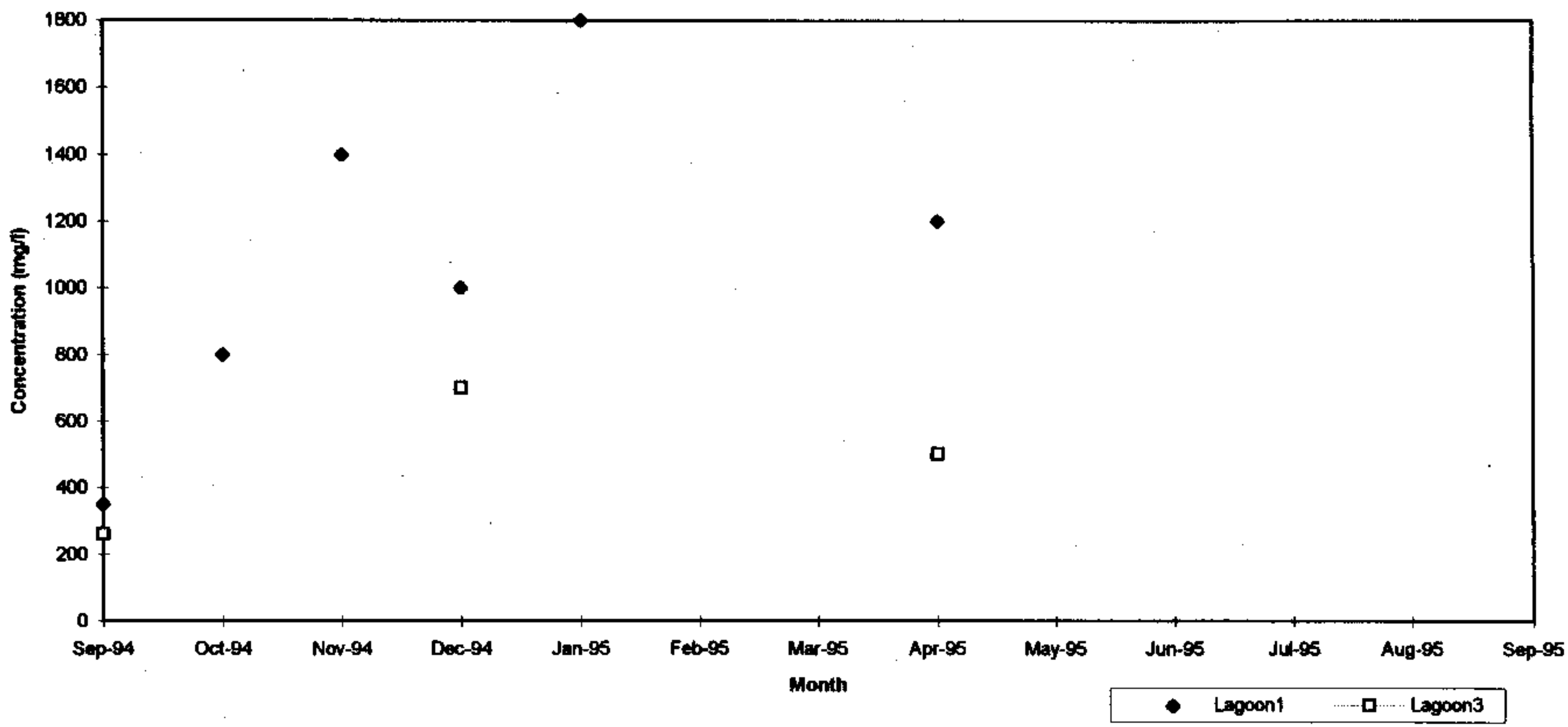


Figure 9. Chemical Oxygen Demand (COD) in Lagoons #1 and #3

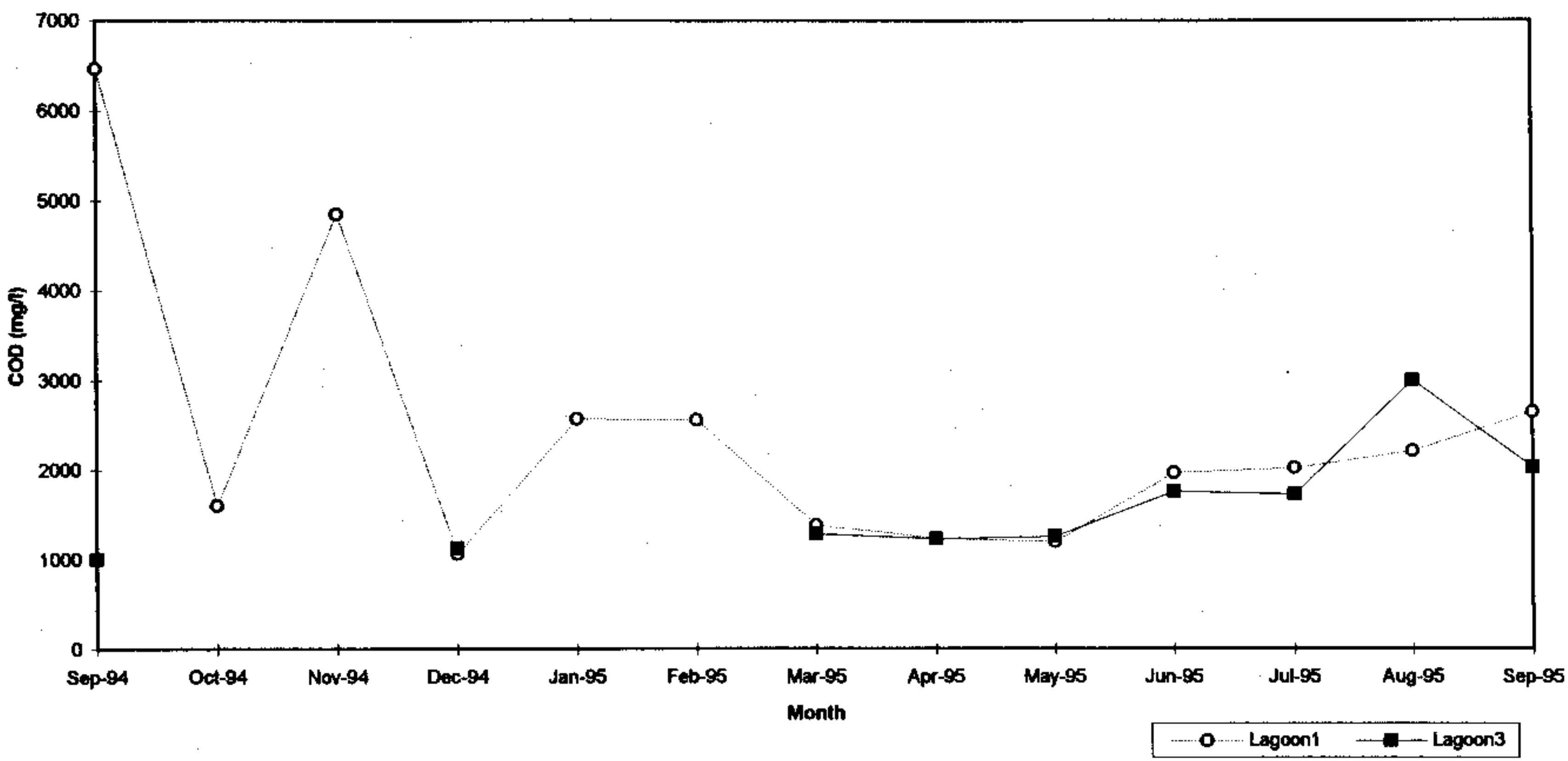


Figure 3. Hydrogen Sulfide (H2S) Concentration in Biogas

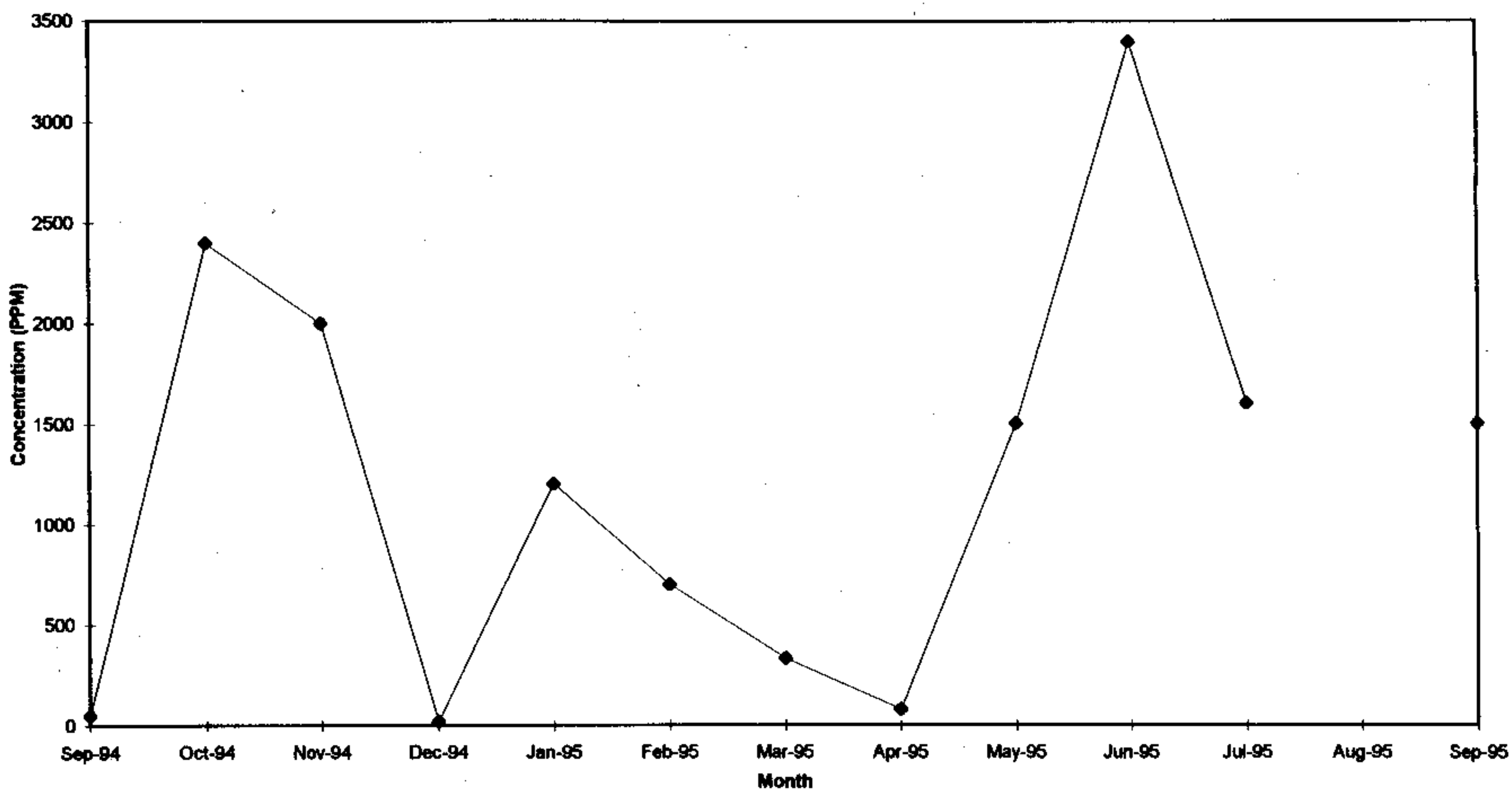


Figure 4. Total Suspended Solids (TSS) and Total Volatile Solids (TVS) in Lagoon #1

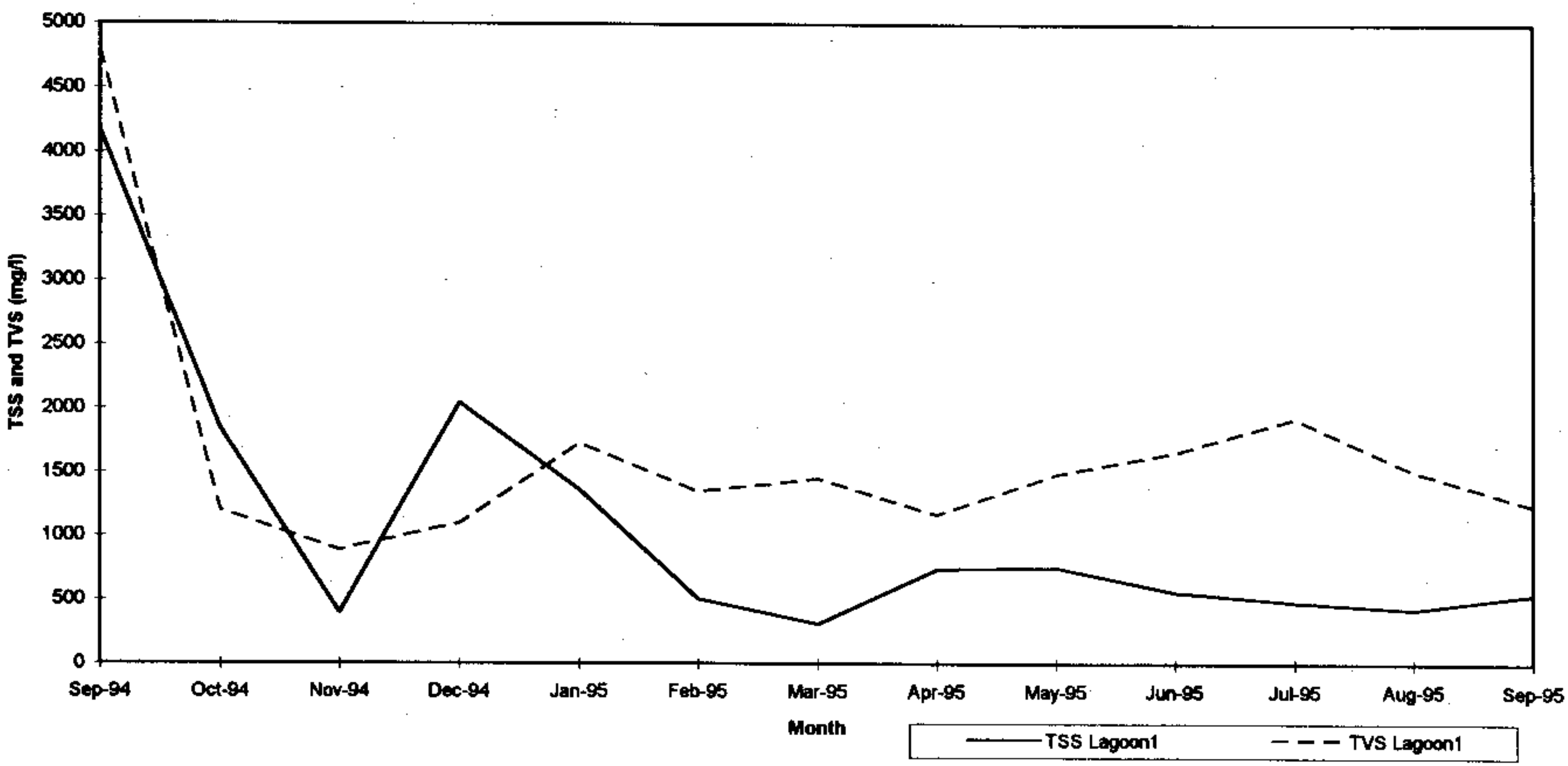
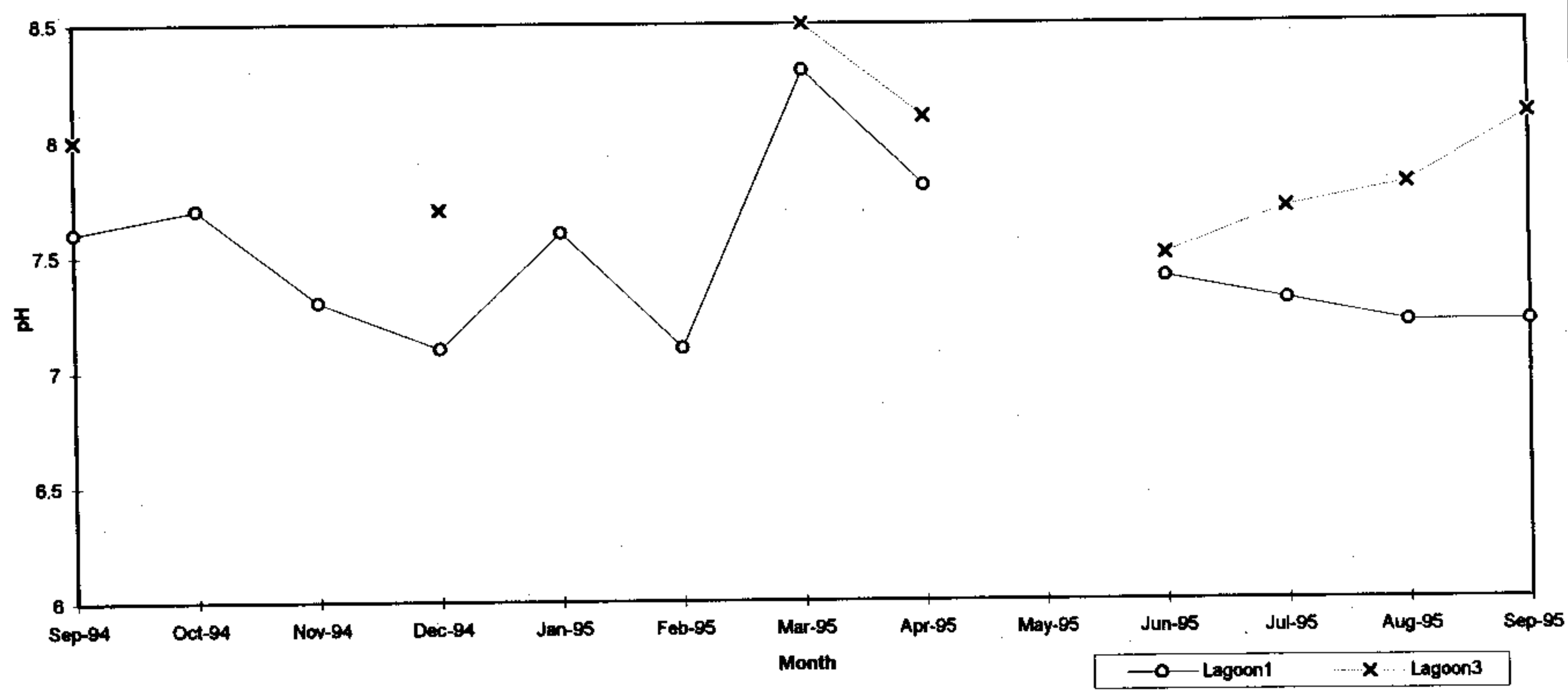


Figure 6. pH Measurements in Lagoons #1 and #3



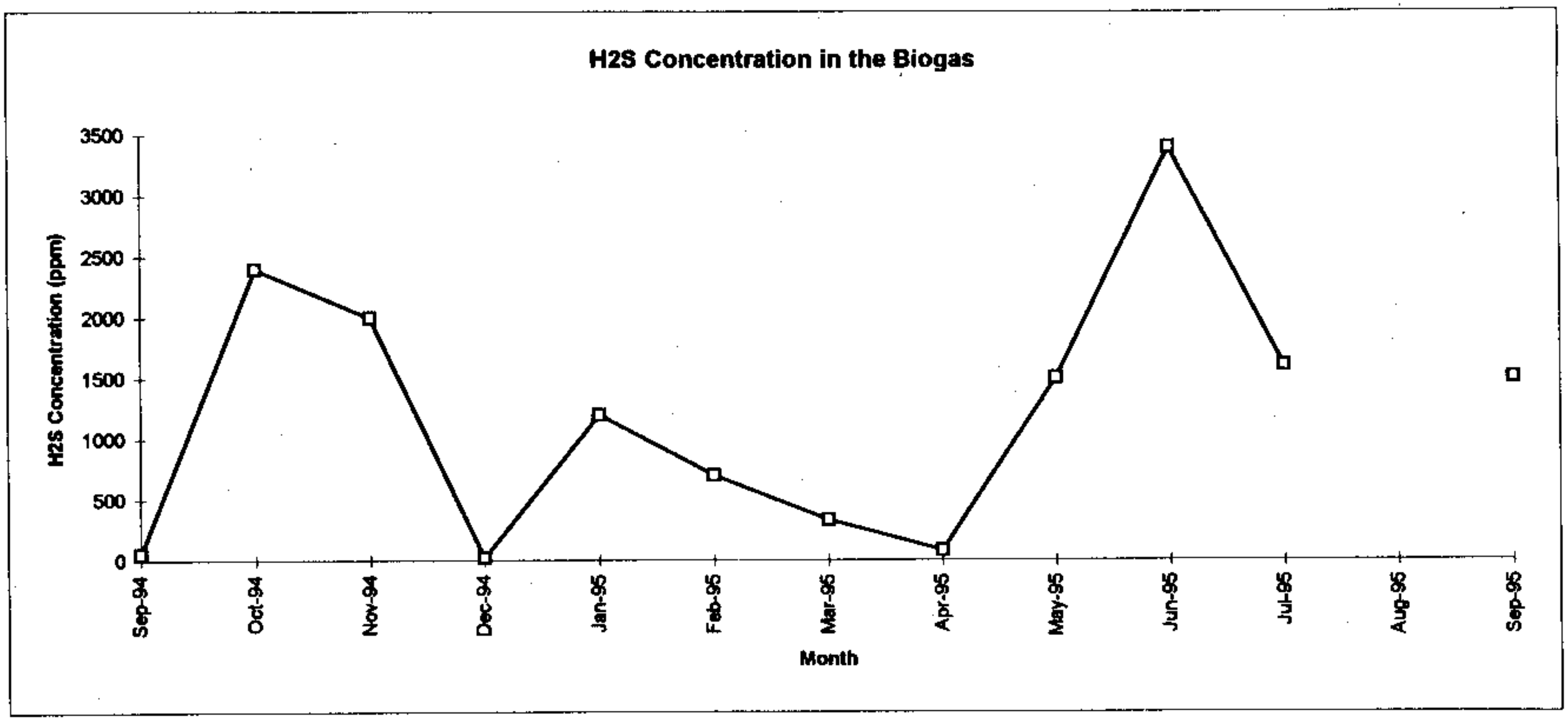
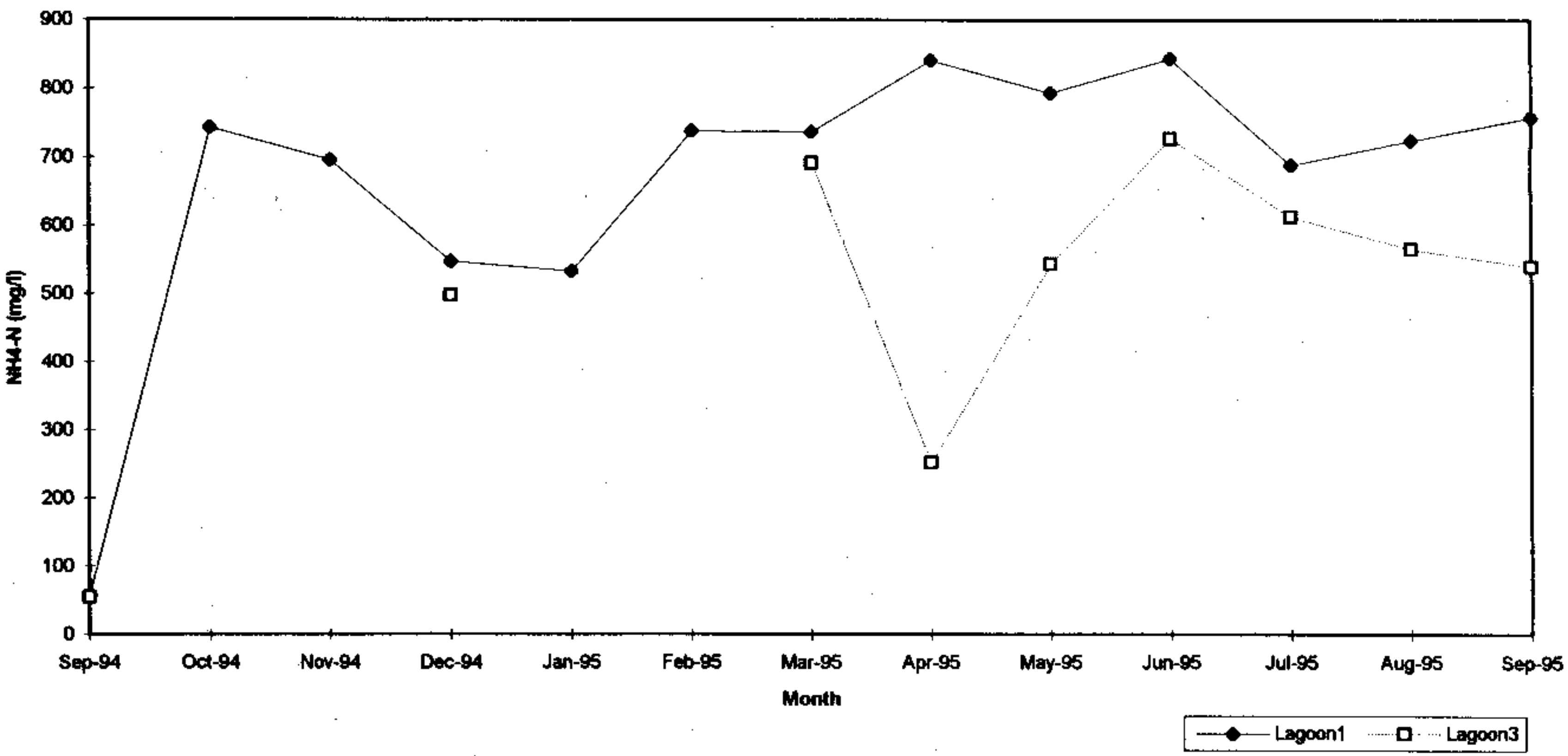

H2S Concentration in the Biogas
H2S Concentration (ppm)
3500
3000
2500
2000
1500
1000
500
0
Sep-94
Oct-94
Nov-94
Dec-94
Jan-95
Feb-95
Mar-95
Apr-95
May-95
Jun-95
Jul-95
Aug-95
Sep-95
Month

Figure 8. Ammonium Nitrogen Measured in Lagoons #1 and #3



Appendix J. Electrical Use Data Collected at 10 California Dairies

Name	Customer 1			**Power Company**		**Milk Barn**	
Region	North Valley			PG&E		**Month**	**Usage (kWh)**
MilkCows	1100					May-94	26160
Milkings	2					Jun-94	27800
Time	9:30am-6:00pm					Jul-94	29960
	9:30pm-6:00am					Aug-94	30360
Type	Flushed feedlanes					Sep-94	26320
	Scraped lots					Oct-94	30520
Equipment						Nov-94	21760
Name	**Quantity**	**HP**	**kW**	**Operation**		Dec-94	29760
Milker	36			Continuous in Milking		Jan-95	24440
Ref. Compressor	3	7.5		Continuous in Milking		Feb-95	21520
Air Compressor	1	5		Intermittent		Mar-95	24600
Vacuum Pump	2	25		Continuous in Milking		Apr-95	25520
Milk Pump	1	2		Continuous in Milking		May-95	30000
Precooler	1	2		Intermittent		Jun-95	26880
Milk Agitator	5	1		Intermittent		**Shop**	
Well Pump	2	10		Intermittent		Jun-94	6225
Lagoon Pump	2	30		Seldom		Jul-94	6992
Ventilation Fan	7	1		Seasonal		Aug-94	6602
Hot Water Heater	2	Gas		Intermittent		Sep-94	5318
Lighting	30		100	Continuous at Night		Oct-94	5546
Lighting	30		80	Continuous at Night		Nov-94	4065
Lighting	1		500	Seldom		Dec-94	5936
Separator Pump	1	30		Intermittent		Jan-95	5185
Electric Gate	1	1		Intermittent		Feb-95	4443
						Mar-95	4436
Summary						Apr-95	4575
Month	**kWh/Cow/Day**					May-95	5501
May-94						Jun-95	5213
Jun-94	1.56					**Flush Pump**	
Jul-94	1.55					Jun-94	6421
Aug-94	1.46					Jul-94	7682
Sep-94	1.47					Aug-94	5142
Oct-94	1.41					Sep-94	1374
Nov-94	1.26					Oct-94	2461
Dec-94	1.43					Nov-94	173
Jan-95	1.38					Dec-94	380
Feb-95	1.14					Jan-95	296
Mar-95	1.50					Feb-95	117
Apr-95	1.47					Mar-95	141
May-95	1.40					Apr-95	1004
Jun-95	1.54					May-95	4417
Average	**1.43**					Jun-95	4848

Schedule	AG5B	40HP		Season A			Season B	
Days	**kWh/day**	**Amount ($)**	**On Peak**	**Partial PK**	**Off Peak**	**On Peak**	**Partial PK**	**Off Peak**
29	902	2422.92	6040	0	20120			
30	927	2517.48	6560	0	21240			
32	936	2625.87	6720	0	23240			
31	979	2662.79	6880	0	23480			
28	940	2346.90	6000	0	20320			
33	925	1915.69	2000	0	7400	0	7160	13960
26	837	1201.00				0	7080	14680
36	827	1588.69				0	9960	19800
30	815	1370.68				0	8800	15640
27	797	1244.98				0	7560	13960
29	848	1312.08				0	8920	15680
29	880	1970.50	3880	0	12280	0	3080	6280
33	909	2537.02	6280	0	23720			
29	927	2364.57	5840	0	21040			
Schedule	AG5B	25HP						
30	208	586.02	1364	0	4861			
32	219	628.39	1428	0	5564			
31	213	618.96	1496	0	5106			
28	190	517.30	1196	0	4122			
33	168	400.58	384	0	1435	0	1525	2202
26	156	264.35				0	1634	2431
36	165	359.79				0	2387	3549
30	173	324.85				0	2247	2938
27	165	293.47				0	1988	2455
29	153	293.40				0	2008	2428
29	158	406.56	671	0	2134	0	693	1077
33	167	524.81	1193	0	4308			
29	180	503.73	1111	0	4102			
Schedule	AG5B	33HP						
30	214	657.27	1321	0	5100			
32	240	651.05	783	0	6899			
31	166	561.37	824	0	4318			
28	49	333.96	280	0	1096			
33	75	289.69	258	0	1485	0	258	460
26	7	108.84				0	55	118
36	11	134.81				0	127	253
30	10	131.33				0	105	191
27	4	123.72				0	38	79
29	5	124.73				0	46	95
29	35	275.47	290	0	659	0	15	40
33	134	520.11	804	0	3613			
29	167	527.07	646	0	4207			

						Separator	Schedule
Billing Dmd	Created Dmd	Avg $/kWh	kWh/Cow/Day	$/Cow/Day		Month	Usage (kWh)
74	56	0.09	0.82	0.08			
68	59	0.09	0.84	0.08		Jun-94	5917
67	61	0.09	0.85	0.07		Jul-94	4664
67	62	0.09	0.89	0.08		Aug-94	4300
62	57	0.09	0.85	0.08		Sep-94	5271
71	57	0.06	0.84	0.05		Oct-94	6167
71	56	0.06	0.76	0.04		Nov-94	7094
71	50	0.05	0.75	0.04		Dec-94	10147
71	49	0.06	0.74	0.04		Jan-95	7506
71	54	0.06	0.72	0.04		Feb-95	6773
56	54	0.05	0.77	0.04		Mar-95	7920
62	56	0.08	0.80	0.06		Apr-95	8933
62	57	0.08	0.83	0.07		May-95	6207
62	60	0.09	0.84	0.07		Jun-95	6895
						Lagoon	Schedule
17	15	0.09	0.19	0.02		Jun-94	5199
17	16	0.09	0.20	0.02		Jul-94	4860
17	16	0.09	0.19	0.02		Aug-94	3931
16	14	0.10	0.17	0.02		Sep-94	5352
19	14	0.07	0.15	0.01		Oct-94	5064
19	15	0.07	0.14	0.01		Nov-94	
19	14	0.06	0.15	0.01		Dec-94	15123
18	16	0.06	0.16	0.01		Jan-95	6858
18	18	0.07	0.15	0.01		Feb-95	0
18	18	0.07	0.14	0.01		Mar-95	11680
16	14	0.09	0.14	0.01		Apr-95	7200
16	15	0.10	0.15	0.01		May-95	5133
16	13	0.10	0.16	0.02		Jun-95	5179
						Calf Barn	Schedule
24	23	0.10	0.19	0.02		Jun-94	535
24	23	0.08	0.22	0.02		Jul-94	640
25	25	0.11	0.15	0.02		Aug-94	683
25	22	0.24	0.04	0.01		Sep-94	666
22	22	0.12	0.07	0.01		Oct-94	841
22	22	0.63	0.01	0.00		Nov-94	761
22	2	0.35	0.01	0.00		Dec-94	1099
22	16	0.44	0.01	0.00		Jan-95	793
22	1	1.06	0.00	0.00		Feb-95	642
22	1	0.88	0.00	0.00		Mar-95	583
25	22	0.27	0.03	0.01		Apr-95	538
25	22	0.12	0.12	0.01		May-95	556
25	24	0.11	0.15	0.02		Jun-95	480

AG5A	30HP							
Days	kWh/day	Amount ($)	On Peak	Partial PK	Off Peak	Avg $/kWh	kWh/Cow/Day	$/Cow/Day
30	197	591.34	522	0	5395	0.10	0.18	0.02
32	146	579.91	789	0	3875	0.12	0.13	0.02
31	139	561.80	792	0	3508	0.13	0.13	0.02
28	188	555.17	507	0	4764	0.11	0.17	0.02
33	187	581.10	403	2289	3479	0.09	0.17	0.02
26	273	508.50	0	2265	4829	0.07	0.25	0.02
36	282	686.63	0	3263	6884	0.07	0.26	0.02
30	250	559.66	0	2745	4561	0.07	0.23	0.02
27	251	527.20	0	2838	3935	0.08	0.23	0.02
29	273	580.30	0	2889	5031	0.07	0.25	0.02
29	308	842.98	1035	1262	6636	0.09	0.28	0.03
33	188	718.69	1089	0	5118	0.12	0.17	0.02
29	238	563.65	129	0	6766	0.08	0.22	0.02
AG4A	25HP							
30	173	548.36	427	0	4772	0.11	0.16	0.02
32	152	651.59	894	0	3966	0.13	0.14	0.02
31	127	528.28	672	0	3259	0.13	0.12	0.02
28	191	700.25	950	0	4402	0.13	0.17	0.02
33	153	519.55	391	1791	2882	0.10	0.14	0.01
62	244	1114.28	0	4652	10471	0.07	0.22	0.02
30	229	228.60	0	2771	4087	0.03	0.21	0.01
27	0	73.80	0	0	0		0.00	0.00
29	403	838.97	0	4811	6869	0.07	0.37	0.03
29	248	915.29	1323	847	5030	0.13	0.23	0.03
33	156	729.96	1115	0	4018	0.14	0.14	0.02
29	179	453.67	82	0	5097	0.09	0.16	0.01
AG1A	2.8HP							
30	18	94.49				0.18	0.02	0.00
32	20	109.36				0.17	0.02	0.00
31	22	115.45				0.17	0.02	0.00
28	24	113.04				0.17	0.02	0.00
33	25	137.43				0.16	0.02	0.00
26	29	123.30				0.16	0.03	0.00
36	31	173.80				0.16	0.03	0.00
30	26	130.46				0.16	0.02	0.00
27	24	109.08				0.17	0.02	0.00
29	20	100.72				0.17	0.02	0.00
29	19	94.72				0.18	0.02	0.00
33	17	97.46				0.18	0.02	0.00
29	17	86.70				0.18	0.02	0.00

Name	Customer 2			**Power Company**		**Milk Barn**	
Region	North Valley			PG&E		**Month**	**Usage (kWh)**
MilkCows	900					Dec-93	46480
Milkings	3					Jan-94	57600
Time	8am-3pm					Feb-94	44480
	4pm-11pm					Mar-94	
	12am-7am					Apr-94	97200
Type	Flushed feedlanes					May-94	49960
	Scraped lots					Jun-94	49960
Equipment						Jul-94	52000
Name	**Quantity**	**HP**	**kW**	**Operation**		Aug-94	45320
Milker	24			Continuous in Milking		Sep-94	54760
Ref. Compressor	5	7.5		Continuous in Milking		Oct-94	47800
Air Compressor	1	10		Intermittent		Nov-94	49440
Vacuum Pump	2	15		Continuous in Milking		Dec-94	49080
Milk Pump	2	2		Continuous in Milking		Jan-95	55200
Ice Bank Pump	2	3		Intermittent		Feb-95	
Milk Agitator	2	1		Intermittent		Mar-95	47240
Well Pump	2	7.5		Intermittent		Apr-95	49520
Sprinkler Pump	1	2		Intermittent		May-95	42640
Sprinkler Pump	1	10		Intermittent		**Separator**	
Barn Cleaning	1	7.5		Intermittent		Dec-93	3698
Lighting	37		250	Continuous at Night		Jan-94	5005
Air Pump	1	1		Seldom		Feb-94	5812
Recycling Pump	1	5		Seldom		Mar-94	6028
Sump Pump	1	30		Intermittent		Apr-94	4495
Screen Mover	2	1		Intermittent		May-94	3129
Well Pump	1	15		Seldom		Jun-94	3121
Manure Pump	1	7.5		Seldom		Jul-94	4179
						Aug-94	3712
Summary						Sep-94	3979
Month	**kWh/Cow/Day**					Oct-94	3103
Dec-93	2.14					Nov-94	3777
Jan-94	2.05					Dec-94	140
Feb-94	2.00					Jan-95	8322
Mar-94						Feb-95	
Apr-94	1.92					Mar-95	3892
May-94	1.90					Apr-95	3715
Jun-94	1.90					May-95	4189
Jul-94	2.08					**Calf Barn**	
Aug-94	1.95					Dec-93	3
Sep-94	1.98					Jan-94	90
Oct-94	2.02					Feb-94	116
Nov-94	2.04					Mar-94	82
Dec-94	1.82					Apr-94	66
Jan-95	2.01					May-94	60
Feb-95						Jun-94	62
Mar-95	1.96					Jul-94	114
Apr-95	1.85					Aug-94	76
May-95	1.80					Sep-94	74
Average	**1.96**					Oct-94	67

							Nov-94	82
							Dec-94	102
							Jan-95	149
							Feb-95	
							Mar-95	73
							Apr-95	71
							May-95	57

Schedule	AG5B		102	96		
Days	kWh/day	Amount ($)	Billing Dmd	Created Dmd	Avg $/kWh	kWh/Cow/Day
26	1788	3443.00			0.07	1.99
34	1694	2894.00			0.05	1.88
28	1589	2336.22			0.05	1.77
62	1568	5015.36			0.05	1.74
31	1612	3465.92			0.07	1.79
31	1612	3883.59			0.08	1.79
30	1733	4152.75			0.08	1.93
28	1619	3712.75			0.08	1.80
33	1659	4239.60			0.08	1.84
28	1707	3889.08			0.08	1.90
29	1705	3288.69			0.07	1.89
30	1636	2539.90			0.05	1.82
33	1673	2770.96			0.05	1.86
29	1629	2447.71			0.05	1.81
32	1548	2545.78			0.05	1.72
29	1470	2956.79			0.07	1.63
Schedule						
26	142	245.68			0.07	0.16
34	147	320.19			0.06	0.16
28	208	364.61			0.06	0.23
33	183	373.38			0.06	0.20
29	155	299.49			0.07	0.17
31	101	286.83			0.09	0.11
31	101	308.33			0.10	0.11
30	139	415.44			0.10	0.15
28	133	364.28			0.10	0.15
33	121	373.43			0.09	0.13
28	111	286.18			0.09	0.12
29	130	296.13			0.08	0.14
		95.14			0.68	
63	132	559.91			0.07	0.15
29	134	266.66			0.07	0.15
32	116	256.35			0.07	0.13
29	144	352.33			0.08	0.16
Schedule						
26	0.1	14.45			4.82	0.00
34	2.6	29.15			0.32	0.00
28	4.1	32.83			0.28	0.00
33	2.5	28.01			0.34	0.00
29	2.3	25.75			0.39	0.00
31	1.9	25.16			0.42	0.00
31	2.0	25.58			0.41	0.00
30	3.8	32.94			0.29	0.00
28	2.7	27.56			0.36	0.00
33	2.2	27.28			0.37	0.00
28	2.4	26.29			0.39	0.00

29	2.8	28.21			0.34	0.00
30	3.4	30.85			0.30	0.00
33	4.5	37.50			0.25	0.01
29	2.5	26.75			0.37	0.00
32	2.2	26.46			0.37	0.00
29	2.0	24.71			0.43	0.00

Name	Customer 3			**Power Company**		**Milk Barn**	
Region	North Valley			PG&E		**Month**	**Usage (kWh)**
MilkCows	910					Dec-93	
Milkings	3					Jan-94	
Time						Feb-94	
						Mar-94	
						Apr-94	
Type	Flushed feedlanes					May-94	
	Scraped lots					Jun-94	
Equipment						Jul-94	
Name	**Quantity**	**HP**	**kW**	**Operation**		Aug-94	
Milker						Sep-94	
Ref. Compressor						Oct-94	
Air Compressor						Nov-94	
Vacuum Pump						Dec-94	
Milk Pump						Jan-95	
Ice Bank Pump						Feb-95	
Milk Agitator						Mar-95	40100
Well Pump						Apr-95	
Sprinkler Pump						May-95	38480
Sprinkler Pump							
Barn Cleaning							
Lighting							
Air Pump							
Recycling Pump							
Sump Pump							
Screen Mover							
Well Pump							
Manure Pump							

Schedule	AG5B			
Days	**kWh/day**	**Amount ($)**	**Avg $/kWh**	**kWh/Cow/Day**
29	1383	2151.60	0.054	1.52
29	1327	2875.61	0.075	1.46

Name	Customer 4			**Power Company**		**Dairy Barn**	
Region	Sacramento Valley			PG&E		**Month**	**Usage (kWh)**
MilkCows	235					Jan-95	7414
Milkings	2					Feb-95	7963
Time	2am-7:30am					Mar-95	6915
	2pm-7:30pm					Apr-95	6633
Type	Flushed feedlanes					May-95	7358
	Scraped lots					Jun-95	7102
Equipment						Jul-95	7528
Name	**Quantity**	**HP**	**kW**	**Operation**		Aug-95	8269
Milker	12			Continuous in Milking		Sep-95	7198
Ref. Compressor	5	2		Continuous in Milking		Oct-95	
Air Compressor	1	5		Intermittent		Nov-95	7966
Vacuum Pump	1	8.5		Continuous in Milking		**Well Pump**	
Milk Pump	1	1		Continuous in Milking		Jan-95	
Precooler	1			Intermittent		Feb-95	991
Milk Agitator	2	1		Intermittent		Mar-95	867
Well Pump	1	20		Intermittent		Apr-95	
Sump Pump	1	1		Intermittent		May-95	3369
Sprinkler Pump	2	5		Intermittent		Jun-95	3585
Hot Water Heater	2		5500	Intermittent		Jul-95	8749
Manure Pump	1	10		Intermittent		Aug-95	
						Sep-95	9418
Summary						Oct-95	9503
Month	**kWh/Cow/Day**					Nov-95	7644
Jan-95	1.02						
Feb-95	1.23						
Mar-95	1.10						
Apr-95	0.97						
May-95	1.47						
Jun-95	1.52						
Jul-95	2.39						
Aug-95	1.10						
Sep-95	2.44						
Oct-95	1.35						
Nov-95	2.08						
Average	**1.51**						

Schedule	AG5B	50HP					
Days	**(kWh/day)**	**Amount ($)**	**Partial PK**	**Demand**	**Off Peak**	**Demand**	**Billing Demand**
31	239	468.67	2553	30	4861	27	30
31	257	489.99	2544	29	5419	30	30
30	231	451.95	2387	28	4528	31	31
29	229	439.69	2260	27	4373	29	31
31	237	470.90	2351	25	4878	28	28
30	237	742.30	1571	26	5531	26	27
29	260	788.89	1713	26	5815	29	29
32	258	838.25	1801	29	6468	28	29
29	248	775.74	1748	25	5450	27	29
32	249	839.39	1847	30	6119	29	30
Schedule	AG5A	20HP	On Peak	Off Peak			
31	32.0	178.42	345	646			
30	28.9	172.49	326	541			
31	108.7	299.52	1315	2054			
30	119.5	433.50	604	2981			
29	301.7	907.10	1649	7100			
29	324.8	937.64	1629	7789			
30	316.8	946.39	1651	7852			
32	238.9	780.70	1299	6345			

Created Demand	Avg $/kWh	kWh/Cow/Day
30	0.063	1.02
30	0.062	1.09
31	0.065	0.98
29	0.066	0.97
28	0.064	1.01
26	0.105	1.01
29	0.105	1.10
29	0.101	1.10
27	0.108	1.06
30	0.105	1.06
	0.180	0.14
	0.199	0.12
	0.089	0.46
	0.121	0.51
	0.104	1.28
	0.100	1.38
	0.100	1.35
	0.102	1.02

Name	Customer 5			**Power Company**		**Dairy Barn**	
Region	Sacramento Valley			PG&E		**Month**	**Usage (kWh)**
MilkCows	318					Nov-94	9229
Milkings	2					Dec-94	10554
Time	12am-7:30am					Jan-95	8893
	12pm-7:30pm					Feb-95	9113
Type	Scraped Feedlanes					Mar-95	8956
						Apr-95	8423
Equipment						May-95	6028
Name	**Quantity**	**HP**	**kW**	**Operation**		Jun-95	8933
Milker	14			Continuous in Milking		Jul-95	8034
Ref. Compressor	1	12		Continuous in Milking		Aug-95	9255
Air Compressor	1	5		Intermittent		Sep-95	8106
Vacuum Pump	1	10		Continuous in Milking		Oct-95	8222
Milk Pump	1	1		Continuous in Milking		Nov-95	9308
Precooler	1			Intermittent		**Well Pump**	
Milk Agitator	1	0.75		Intermittent		Aug-95	849
Well Pump				Intermittent		Sep-95	1093
Sump Pump				Intermittent		Oct-95	947
Sprinkler Pump	1	5		Intermittent		Nov-95	1016
Hot Water Heater	1	Gas		Intermittent		Dec-95	1173
Manure Pump				Intermittent		**Calf Pens**	
						Jan-95	101
Summary						Feb-95	84
Month	**kWh/Cow/Day**					Mar-95	92
Jan-95	0.94					Apr-95	88
Feb-95	0.93					May-95	61
Mar-95	0.95					Jun-95	36
Apr-95	0.96					Jul-95	56
May-95	0.96					Aug-95	59
Jun-95	0.94					Sep-95	92
Jul-95	0.88					Oct-95	103
Aug-95	1.01					Nov-95	166
Sep-95	1.00					Dec-95	96
Oct-95	0.98						
Nov-95	1.01						
Average	**0.96**						

Schedule	AG5B			Winter				Summer	
Days	**kWh/day**	**Amount ($)**	**On Peak**	**Demand**	**Off Peak**	**Demand**	**On Peak**	**Demand**	**Off Peak**
31	298	539.03	3389	28	5840	26			
33	320	591.50	3467	7	7085	24			
30	296	523.83	3176	25	5718	27			
31	294	531.40	3080	25	6033	27			
30	299	528.29	3381	25	5575	25			
28	301	809.03	477	26	924	28	1859	25	5163
20	301	586.22					1444	26	4584
30	298	893.23					2308	26	6625
29	277	839.94					2171	26	5863
32	289	887.49					2150	25	7105
29	280	827.05					2072	24	6034
30	274	725.14					1441	23	4094
33	282	536.35					3254	23	6054
Schedule	AG1A	3HP							
29	29.3	139.61							
32	34.2	174.21							
29	32.7	153.50							
30	33.9	163.09							
33	35.5	184.95							
Schedule	A1	Lamps							
30	3.4	19.20							
31	2.7	17.33							
30	3.1	18.21							
28	3.1	17.77							
20	3.1	17.43							
30	1.2	11.10							
29	1.9	17.07							
32	1.8	17.55							
29	3.2	22.84							
30	3.4	24.60							
33	5.0	31.90							
33	2.9	18.65							

Demand	Billing Dmd	Created Dmd	Avg $/kWh	kWh/Cow/Day
	28	28	0.058	0.94
	28	24	0.056	1.01
	28	27	0.059	0.93
	28	27	0.058	0.92
	28	25	0.059	0.94
27	27	28	0.096	0.95
24	26	26	0.097	0.95
26	26	26	0.100	0.94
25	26	26	0.105	0.87
26	26	26	0.096	0.91
26	26	26	0.102	0.88
24	28	25	0.088	0.86
23	27	23	0.058	0.89
			0.164	0.09
			0.159	0.11
			0.162	0.10
			0.161	0.11
			0.158	0.11
			0.190	0.01
			0.206	0.01
			0.198	0.01
			0.202	0.01
			0.286	0.01
			0.308	0.00
			0.305	0.01
			0.297	0.01
			0.248	0.01
			0.239	0.01
			0.192	0.02
			0.194	0.01

Name	Customer 6			**Power Company**		**Month**
Region	Sacramento Valley			PG&E		**Dairy Barn**
MilkCows	575	Jersey				Jan-95
Milkings	3					Feb-95
Time	23 hrs/day					Mar-95
						Apr-95
						May-95
Type	Flushed feedlanes					Jun-95
	Scraped lots					Jul-95
Equipment						Aug-95
Name	**Quantity**	**HP**	**kW**	**Operation**		Sep-95
Milker				Continuous in Milking		Oct-95
Ref. Compressor	2	10		Continuous in Milking		Nov-95
Air Compressor	1	3		Intermittent		**Separator**
Vacuum Pump	1	15		Continuous in Milking		Jan-95
Milk Pump	1	1		Continuous in Milking		Feb-95
Hot Water Heater	1		4500	Intermittent		Mar-95
Sprinkler Pump	1	5		Intermittent		Apr-95
Agitators	3	0.5		Intermittent		May-95
Hose Pump	1	1		Intermittent		Jun-95
Well Pump	1	20		Intermittent		Jul-95
Well Pump	1	1		Intermittent		Aug-95
Feed Pump	1	3		Intermittent		Sep-95
						Oct-95
Summary						Nov-95
Month	**kWh/Cow/Day**					**Well Pumps**
Jan-95	1.28					Jan-95
Feb-95	1.37					Feb-95
Mar-95	1.33					Mar-95
Apr-95	1.28					Apr-95
May-95						May-95
Jun-95	1.28					Jun-95
Jul-95	2.00					Jul-95
Aug-95	2.19					Aug-95
Sep-95	1.96					Sep-95
Oct-95	1.89					Oct-95
Nov-95	1.96					Nov-95
Average	**1.65**					**Pump**
						Jan-95
						Feb-95
						Mar-95
						Apr-95
						May-95
						Jun-95
						Jul-95
						Aug-95
						Sep-95
						Oct-95
						Nov-95

Usage (kWh)	Days	kWh/day	Amount ($)	Billing Dmd	Created Dmd		Avg $/kWh
	Schedule	AG5B	31HP	kW	kW		
16459	31	531	879.70	36	36		0.053
17109	32	535	902.65	36	35		0.053
16937	32	529	925.47	36	36		0.055
15520	30	517	838.34	36	33		0.054
14621	29	504	806.35	36	34		0.055
14476	29	499	951.90	36	35		0.066
11375	21	542	954.92	36	35		0.084
19171	32	599	1528.44	36	36		0.080
18129	29	625	1519.92	37	37		0.084
19103	30	637	1584.64	38	38		0.083
19968	32	624	1633.98	39	39		0.082
	Schedule	AG5B	32HP				
3673	31	118	267.34	20	20		0.073
5190	32	162	341.99	22	22		0.066
4916	32	154	348.04	25	25		0.071
4307	30	144	316.36	25	25		0.073
8367	58	144	707.93	39	19		0.085
3249	21	155	438.13	39	24		0.135
4738	32	148	681.32	39	22		0.144
3311	29	114	577.71	39	23		0.174
5046	30	168	666.34	39	20		0.132
5292	32	165	666.69	39	19		0.126
	Schedule	AG5A		**On Peak**	**Partial Peak**	**Off Peak**	
2647	31	85.4	267.96	0	1063	1584	0.101
2846	32	88.9	277.60	0	1108	1738	0.098
2635	32	82.3	267.87	0	1102	1533	0.102
2254	30	75.1	249.62	0	1033	1221	0.111
2078	29	71.7	239.23	0	834	1244	0.115
2691	29	92.8	300.12	146	809	1736	0.112
5242	21	249.6	477.08	429	0	4813	0.091
8811	32	275.3	730.79	725	0	8086	0.083
5799	29	200.0	585.75	774	0	5025	0.101
5157	30	171.9	529.96	659	0	4498	0.103
6157	32	192.4	581.14	658	0	5499	0.094
	Schedule	AG4A					
0	31	0	62.80	0	0	0	
0	32	0	62.80	0	0	0	
0	32	0	62.80	0	0	0	
0	29	0	62.80	0	0	0	
0	29	0	64.18	0	0	0	
4266	21	203	342.29	21	0	4245	0.080
7559	32	236	603.21	80	0	7479	0.080
5410	29	187	457.40	82	0	5328	0.085
3244	30	108	324.50	136	0	3108	0.100
4670	32	146	401.33	61	0	4609	0.086

kWh/Cow/Day
0.92
0.93
0.92
0.90
0.88
0.87
0.94
1.04
1.09
1.11
1.09
0.21
0.28
0.27
0.25
0.00
0.25
0.27
0.26
0.20
0.29
0.29
0.15
0.15
0.14
0.13
0.12
0.16
0.43
0.48
0.35
0.30
0.33
0.00
0.00
0.00
0.00
0.00
0.00
0.35
0.41
0.32
0.19
0.25

Name	Customer 7			**Power Company**		**Month**
Region	Sacramento Valley			PG&E		**Dairy Barn**
MilkCows	450	Jersey	Cows			Dec-94
Milkings	3					Jan-95
Time	20 hrs/day					Feb-95
						Mar-95
						Apr-95
Type	Flushed feedlanes					May-95
	Scraped lots					Jun-95
Equipment						Jul-95
Name	**Quantity**	**HP**	**kW**	**Operation**		Aug-95
Milker				Continuous in Milking		Sep-95
Ref. Compressor	2	10		Continuous in Milking		Oct-95
Air Compressor	1	3		Intermittent		Nov-95
Vacuum Pump	1	15		Continuous in Milking		Dec-95
Milk Pump	1	1		Continuous in Milking		
Hot Water Heater	1		4500	Intermittent		
Sprinkler Pump	1	5		Intermittent		
Agitators	3	0.5		Intermittent		
Hose Pump	1	1		Intermittent		
Well Pump	1	20		Intermittent		
Well Pump	1	1		Intermittent		
Feed Pump	1	3		Intermittent		
Summary						
Month	**kWh/Cow/d**					
Dec-94	0.87					
Jan-95	0.12					
Feb-95	0.76					
Mar-95	0.78					
Apr-95	0.76					
May-95	0.79					
Jun-95	0.84					
Jul-95	1.02					
Aug-95	1.02					
Sep-95	0.98					
Oct-95	1.01					
Nov-95	0.98					
Dec-95	0.96					
Average	**0.84**					
	Milk Barn Only					

Usage (kWh)	Days	kWh/day	Amount ($)	Billing Dmd	Created Dmd	Avg $/kWh	kWh/Cow/d
	Schedule	AG5B	31HP	kW	kW		
12192	31	393	699.66	36	36	0.057	0.87
850	16	53	108.70	0	0	0.128	0.12
10982	32	343	651.91	36	34	0.059	0.76
10471	30	349	622.43	36	33	0.059	0.78
9572	28	342	588.16	36	34	0.061	0.76
10689	30	356	775.55	32	32	0.073	0.79
11327	30	378	1110.24	34	34	0.098	0.84
9611	21	458	832.21	34	30	0.087	1.02
14685	32	459	1210.39	34	30	0.082	1.02
12818	29	442	1104.43	34	30	0.086	0.98
13598	30	453	1154.19	34	31	0.085	1.01
14124	32	441	1164.70	34	31	0.082	0.98
13334	31	430	744.16	34	30	0.056	0.96

Name	Customer 8			Power Company	Summary		Dairy
Region	Sacramento Valley			PG&E	kWh/Cow/d		Month
MilkCows	360				1.85		Dec-93
Milkings	2				1.72		Jan-94
Time	1:00am-5:30am				1.66		Feb-94
	1:00pm-5:30pm				1.65		Mar-94
Type	Scraped Feedlanes				1.59		Apr-94
	Freestalls				1.67		May-94
Equipment					1.75		Jun-94
Name	Quantity	HP	kW	Operation	1.47		Jul-94
Milker				Continuous in Milking	1.49		Aug-94
Ref. Compressor	3	7.5		Continuous in Milking	1.24		Sep-94
Air Compressor	1	10		Intermittent	1.18		Oct-94
Vacuum Pump	2	5		Continuous in Milking	1.26		Nov-94
Milk Pump	2	0.75		Continuous in Milking	1.28		Dec-94
Precooler	2			Intermittent	1.25		Jan-95
Milk Agitator	2	1		Intermittent	1.23		Feb-95
Tank Washer	2	0.5		Intermittent	1.27		Mar-95
Sprinkler	1	0.5		Intermittent	1.21		Apr-95
Sump Pump	1	5		Intermittent	1.16		May-95
Barn Hose	1	0.5		Intermittent	1.21		Jun-95
					1.37		Jul-95
					1.36		Aug-95
					1.30		Sep-95
					1.18		Oct-95
					1.14		Nov-95
					1.10		Dec-95
				Average	**1.38**		
					1.23	1995	
					1.50	1994	

	Schedule	AG5B	52.1HP		Season A			Season B
Usage (kWh)	**Days**	**kWh/day**	**Amount ($)**	**On Peak**	**Partial PK**	**Off Peak**	**On Peak**	**Partial PK**
22000	33	667						
18600	30	620						
17960	30	599						
18360	31	592						
16640	29	574						
18000	30	600						
17640	28	630						
15840	30	528						
15520	29	535						
14280	32	446						
11920	28	426						
13120	29	452						
16080	35	459	971.24				0	5360
12560	28	449	733.99				0	4120
14600	33	442	858.88				0	5040
13240	29	457	803.71				0	4800
12680	29	437	771.18				0	4600
11680	28	417	1234.66	2760	0	7040	0	640
12680	29	437	1380.44	3400	0	9280		
16760	34	493	1706.07	4160	0	12600		
14160	29	488	1420.07	3600	0	10560		
14920	32	466	1460.21	3480	0	11440		
11880	28	424	1289.36	3160	0	8720		
12360	30	412	916.88	960	0	2520	0	3160
13480	34	396	826.54				0	4280

Off Peak	Billing Dmd	Created Dmd	Avg $/kWh
10720	53	46	0.060
8440	50	48	0.058
9560	50	42	0.059
8440	50	44	0.061
8080	48	42	0.061
1240	54	38	0.106
	53	40	0.109
	52	47	0.102
	52	47	0.100
	48	44	0.098
	47	42	0.109
5720	48	42	0.074
9200	48	40	0.061

Name	Customer 9			**Power Company**	**Summary**		**Dairy**
Region	Sacramento Valley			PG&E	**kWh/Cow/d**		**Month**
MilkCows	500				1.07		Dec-93
Milkings	2				1.10		Jan-94
Time	1:15am-7:30am				1.09		Feb-94
	1:15pm-7:30pm						Mar-94
Type	Flushed Feedlanes						Apr-94
	Freestalls						May-94
Equipment							Jun-94
Name	**Quantity**	**HP**	**kW**	**Operation**	1.27		Jul-94
Ref. Compressor	1	5		Continuous in Milking	1.26		Aug-94
Ref. Compressor	1	7.5		Continuous in Milking	1.32		Sep-94
Air Compressor				Intermittent	1.21		Oct-94
Vacuum Pump	1	15		Continuous in Milking	1.20		Nov-94
Milk Pump	2	1		Continuous in Milking	1.27		Dec-94
Precooler	1			Intermittent	1.26		Jan-95
Milk Agitator	1	1		Intermittent	1.16		Feb-95
Tank Washer	1	1		Intermittent			Mar-95
Sprinkler	1	10		Intermittent			Apr-95
Sump Pump				Intermittent			May-95
Barn Hose	1	10		Intermittent			Jun-95
Well Pump	2	5		Intermittent	1.46		Jul-95
Water Heater	1		4500		1.13		Aug-95
					1.08		Sep-95
					1.05		Oct-95
					1.01		Nov-95
					1.05		Dec-95
					1.12		Jan-96
				Average	**1.17**		

	Schedule	AG5B			Season A			Season B
Usage (kWh)	Days	kWh/day	Amount ($)	On Peak	Partial PK	Off Peak	On Peak	Partial PK
15480	29	534						
16480	30	549						
16960	31	547						
19680	31	635						
19560	31	631						
21840	33	662						
18120	30	604						
16800	28	600						
21520	34	633	1170.98				0	7200
18280	29	630	1046.86				0	6920
18520	32	579	1048.18				0	6120
24120	33	731	2103.8	5360	0	18760		
15760	28	563	1570.76	3720	0	12040		
16200	30	540	1610.96	3920	0	12280		
15160	29	523	1557.9	3840	0	11320		
16160	32	505	1188.29	1440	0	4320	0	3680
15720	30	524	934.74				0	5640
17880	32	559	996.19				0	5720

Off Peak	Billing Dmd	Created Dmd	Avg $/kWh
14320	55	52	0.054
11360	56	56	0.057
12400	56	53	0.057
	53	52	0.087
	53	51	0.100
	53	50	0.099
	53	52	0.103
6720	56	50	0.074
10080	56	50	0.059
12160	56	51	0.056

Name	Customer 10			**Power Company**	**Summary**		**Month**
Region	Sacramento Valley			PG&E	**kWh/Cow/d**		**Dairy Barn**
MilkCows	110				0.94		Dec-93
Milkings	2				0.94		Jan-94
Time	4:00pm-7:00pm				0.93		Feb-94
	5:00am-9:00am				0.98		Mar-94
					0.99		Apr-94
Type	Scraped Feedlane				1.01		May-94
	Pastured				1.06		Jun-94
Equipment					1.09		Jul-94
Name	**Quantity**	**HP**	**kW**	**Operation**	1.04		Aug-94
Milker	5			Continuous in Milking	0.94		Sep-94
Ref. Compressor	2	3		Continuous in Milking	0.92		Oct-94
Air Compressor				Intermittent	0.89		Nov-94
Vacuum Pump	1	5		Continuous in Milking	0.92		Dec-94
Milk Pump	1	1		Continuous in Milking	0.87		Jan-95
Hot Water Heater	1		4500	Intermittent	0.88		Feb-95
Tank Washer	1	0.75		Intermittent	0.97		Mar-95
Agitators	1	0.5		Intermittent	0.93		Apr-95
Hose Pump	1	1		Intermittent	0.97		May-95
Well Pump	1	1		Intermittent	0.97		Jun-95
Fluorescents	8		40	Continuous at night	1.07		Jul-95
Regular Bulbs	4		200	Intermittent	1.01		Aug-95
Flood Lights	3		100	Intermittent	1.04		Sep-95
Mercury Bulb	1		150	Intermittent	1.05		Oct-95
					0.99		Nov-95
				Average	**0.98**		

Usage (kWh)	Days	kWh/day	Amount ($)	
	Schedule	A1	15HP	Avg $/kWh
3325	32	104		
3325	32	104		
3163	31	102		
3337	31	108		
3156	29	109		
3320	30	111		
3733	32	117		
3483	29	120		
3881	34	114		
2999	29	103		
2745	27	102		
3035	31	98		
3247	32	101	364.20	0.112
2970	31	96	335.63	0.113
2807	29	97	315.37	0.112
3315	31	107	371.66	0.112
2956	29	102	378.45	0.128
3195	30	107	519.27	0.163
3398	32	106	551.75	0.162
3428	29	118	556.55	0.162
3328	30	111	540.55	0.162
3326	29	115	540.23	0.162
3680	32	115	556.36	0.151
3272	30	109	366.94	0.112